FEBRUARY, 1925 MEMOIR 87

CORNELL UNIVERSITY

AGRICULTURAL EXPERIMENT STATION

STUDIES IN THE TRANSPLANTING OF VEGETABLE PLANTS

W. E. LOOMIS

ITHACA, NEW YORK
PUBLISHED BY THE UNIVERSITY
Received for publication July 1, 1924

781
81L
ASSED

CONTENTS

	PAGE
Previous opinions and experimental results	3
The problem and the method of attack	4
General methods	5
Outline of experimental work	6
Studies on the effect of transplanting	7
Transplanting in greenhouse beds	7
Effects of transplanting upon root branching	9
Effects of transplanting upon ratio of roots to tops	9
Relation of maturity of plant to effect of transplanting	12
Relation of rate of growth to effect of transplanting	15
Transplanting tests in the field	16
Growing the plants	16
Interpretation of the data	17
Field work with cabbage	19
Field work with celery	21
Field work with tomatoes	22
Field work with beans	26
Effect of the larger, more branched root systems resulting from transplanting, upon performance in the field	26
Effects of wilting and slow drying with transplanting	28
The relation of hardening, transpiration, and other properties of the top to transplanting	30
Sap concentration in hardened and in tender vegetable plants	30
Imbibition of water by the dried tissue of hardened and tender vegetable plants	33
Water loss from hardened and from tender plants	36
Drying of cut plants	36
Transpiration of living, hardened and tender vegetable plants	37
Transpiration after transplanting	40
Root replacement by hardened and tender plants	42
Carbohydrate accumulation during hardening	44
Studies of root growth and root structure as affecting transplanting	46
Root replacement and its relation to transplanting	46
Studies of the cutinization and suberization of the roots of certain vegetable plants	50
Discussion	56
Growth responses following transplanting	56
Leaf characteristics influencing the effect of transplanting	57
Root characteristics influencing the effect of transplanting	58
Conclusions	59
Summary	60
Bibliography	63

Studies in the Transplanting of Vegetable Plants

A THESIS

Presented to the Faculty of the Graduate School of Cornell University for the degree of DOCTOR OF PHILOSOPHY

BY

WALTER EARL LOOMIS

Published by the New York State College of Agriculture, Cornell University.

Ithaca, N. Y. February 1925

Digitized by the Internet Archive
in 2025

https://archive.org/details/studiesintranspl0000welo

STUDIES IN THE TRANSPLANTING OF VEGETABLE PLANTS[1]

W. E. Loomis

The acreage of vegetables produced from transplanted plants, the value of such crops, and the very considerable cost of growing the plants, give the practice of transplanting a high place in the economics of vegetable production. In the census of 1919, those crops which are commonly transplanted — sweet potatoes, tomatoes, cabbage, celery, peppers, cauliflower, eggplant, and brussels sprouts — are reported as having an aggregate acreage of 1,289,000, and a value of nearly $200,000,000. These figures represent 57 per cent of the acreage and 63 per cent of the value of all vegetables other than irish potatoes. The value of work of this sort is further augmented by the fact that the subject has been inadequately covered by previous investigations. Although a number of men have reported data on different phases of transplanting, these have been largely fragmentary and incidental and have been lacking in such studies of the plants as might explain the results obtained.

PREVIOUS OPINIONS AND EXPERIMENTAL RESULTS

The groundwork of our practices in vegetable production rests upon the methods developed by Old World gardeners. Their ideas were brought to America and became incorporated into the earlier literature. Because the industry has been generally prosperous in spite of them, much of the unnecessary detail and inclination to extremes have been preserved. There is at present, however, a tendency to eliminate superfluous and frequently injurious practices, such as pruning and suckering, excessive cultivation, and overheavy fertilization. In order to determine whether this same tendency is manifesting itself in regard to transplanting, questionnaires were sent to a number of progressive growers throughout the country. The answers received are summarized in table 1.

These opinions show considerable divergence from earlier recommendations, when we were told to "transplant freely — nearly all vege-

Author's acknowledgments. The writer is pleased to acknowledge his indebtedness to Professor H. C. Thompson and to Dr. O. F. Curtis, who have rendered invaluable service, both in reviewing and criticizing the work and in supplying facilities for its continuance. Professor Thompson, under whose direction the problem was attacked, has been especially liberal in supplying apparatus and greenhouse and field space, and in relieving the writer of routine requirements, thus allowing him to concentrate his attention upon investigational work. Thanks are also due Dr. Knudson for suggestions and criticisms during the earlier part of the work and to Dr. H. H. Love for his assistance in the statistical analysis of the data.

[1] Also presented to the Graduate School of Cornell University in partial fulfillment of the requirements for the degree of doctor of philosophy.

TABLE 1. Growers' Answers to Questionnaire on Effects of Transplanting

Does transplanting cause	Yes	No
More thrifty growth	15	11
Better root systems	25	1 (?)
Earlier maturity	13	10
Heavier yields	5	18

tables are the better for it," to "transplant to induce productiveness," and that "frequent transplanting is of great benefit but should not be done merely to give the plants more room."

Of the writers basing their recommendations upon data obtained, Bailey and Lodeman (1891) and Bailey and Corbett (1892) were rather strongly in favor of transplanting. Their data, however, do not uphold their conclusions and could more easily be used against the practice than for it. Bishop (1890) and Brunk (1891) obtained rather clear-cut results in two years of work with tomatoes, which indicated earlier fruit and larger yield when the seed was sown in pots and not disturbed, than when the plants were transplanted in the seedling stage and again when moved to the field, but were otherwise handled similarly. Munson (1892) reported that frequent transplanting was markedly beneficial. His data do not support the statement. According to a later report (Munson, 1894), tomatoes at 75 cents a bushel gave a return of $21.83 an acre for handling in pots with minimum transplanting, and as a result of the work of 1892 and 1893 Munson reversed his conclusions of the first year. Newman (1899) found it preferable to grow tomato plants in boxes, and noted that plants transplanted twice gave as good results as those with three transplantings in spite of greater crowding. Troop (1901) found slight reductions in yield from extra transplantings before setting to the field. Pelton, in personal correspondence, 1922, reported that the practice of severe root pruning of cabbage before setting to the field retarded maturity without affecting the total yield. Boyle (1913), in some indirect comparisons, decided that nothing was to be gained by transplanting, and reported an increase of 38 per cent from plants grown in bands without disturbance over those transplanted three times. Cranefield (1899) found that frequent transplanting gave a decrease in yield with tomatoes, lettuce, cabbage, and some other crops.

THE PROBLEM AND THE METHOD OF ATTACK

Transplanting, like most cultural questions, may be approached from the practical viewpoint or from the purely theoretical. A combination of the two has been attempted in this investigation. The problem has

been to determine the immediate and secondary effects of transplanting upon the root and top growth of vegetable plants, and to correlate these effects with the structural and physiological adaptations of the crops being studied.

General methods

One of the principal reasons given for transplanting is the provision of more room for the growing plants. In a critical study of the direct effect of transplanting, however, the space factor must be kept constant, and it has been the practice throughout this work to maintain equivalent spacing of all treatments at all times. Uniformity of exposure and initial vigor are also necessary. The first has been obtained by the use of guards around all transplanting treatments, both indoors and out. Some work on plant selection indicated that considerable variation might arise from differences in initial vigor. This has been avoided by choosing uniform seedlings for the experiments. To eliminate, as much as possible, the personal element in such selection, the seed for all treatments has been sown in place, either in the greenhouse beds or in pots or flats when grown for the field, and all have been thinned in the same manner and at the same time. Such a practice has also insured comparable conditions during the seedling stage. In no instance have the control rows been spaced farther apart than every fourth row, and in the comparisons including a number of treatments, such as the effect of transplanting at different ages, it has been the practice to check with every third row.

Transplantings have been given in relation to stage of maturity rather than age. The actual age of the plants has varied with both the crop and the growing conditions, but for the standard comparisons the writer has used what are designated as the "two-" and the "six-week stages" for the first and the second transplantings, respectively. The two-week stage represents the seedlings as commonly picked out, when the seed leaves are well developed but before the true leaves show as more than a bud. The six-week stage represents the size at which the plants would begin to crowd if growing with a 2-by-2-inch spacing, or $2\frac{1}{2}$ to 3 inches high for cabbages, $3\frac{1}{2}$ to 4 inches for tomatoes, and proportionate sizes for other crops. The "once transplanted when large," *TL* treatment, was given at the six-week stage. (Figure 1.)

The number of plants in a treatment has varied from eight in the small pots to ten or more in the field and fifteen or twenty in the greenhouse tests. Whenever possible, duplicate determinations were made in the greenhouse work, and most of the experiments have been repeated several times. Four or more repetitions were used in all field work. Readings have, in general, been to the nearest gram green weight, and averages are calculated to tenths or hundredths. Probable error, unless otherwise stated, has been calculated with a modified form of the Bessel's formula,

FIGURE 1. TOMATO PLANTS IN THE SIX-WEEK STAGE
This shows the size of the plants at this stage and the method of handling pot-grown plants for the field

proposed by Dr. H. H. Love, in which the probable error of the mean is found from the equation

$$(1.) \qquad PE_m = \pm .6745\sqrt{\frac{\frac{\Sigma R^2 - M^2}{n}}{n-1}}$$

where R is the weight of individual variants, n equals the total number, and M is the mean of the population. Bessel's method has been generally employed rather than Student's because the small number of plants used has made it possible to maintain similar soil conditions and because the comparisons averaged have been made, usually, in a single season, so that systematic errors were not important.

In the summaries, the PE of an average for which the individual errors are not given is calculated from equation 1. When these errors are given, the approximation formula

$$(2.) \qquad EM_m = \pm\sqrt{\frac{a^2 + b^2 + c^2 \ldots}{n}}$$

is used, where a, b, c, and so forth, are the errors of the several means averaged. When Bessel's formula is used, the odds are obtained with Pearl's table (1923) from the ratio of the observed difference to the error of the difference. This error is obtained from the formula

$$(3.) \qquad PE_d = \pm\sqrt{a^2 + b^2}$$

where a and b are the errors of the treatments compared.

Outline of experimental work

The experimental work falls naturally into three groups, of which the first includes tests of the effect of transplanting on root and top growth

in the greenhouse and in the field; the second, studies of transpiration, hardening, and other properties of the top which may be concerned in transplanting responses; and the third, a study of root structure and root branching as affecting the ability of the roots to absorb moisture and the rate of replacement of mutilated root systems.

STUDIES ON THE EFFECT OF TRANSPLANTING

Transplanting in greenhouse beds

Starting in the fall of 1922 and continuing through the summer of 1923, a number of tests were made in ground beds in the greenhouse, in which the four standard treatments, check (*C*), once transplanted (*1T*), twice transplanted (*2T*), and once transplanted large (*TL*), were compared. The first transplanting was given at the two-week stage, the actual age from seeding varying from one week for corn, melons, and rapidly growing plants, to five weeks for celery. The late transplanting was done at the six-week stage; the actual age of the plants is given in the tables. The plants were grown in rows 12 inches apart, and were spaced 6 to 12 inches in the row. End plants and outside rows were invariably discarded. The number of plants used in each treatment, the total weeks of growth,

TABLE 2. TRANSPLANTING IN GREENHOUSE BEDS

Crop	Number of plants*	Age at harvest (weeks)	Age at last transplanting (weeks)	Green weight check (grams)	Transplanting treatments, as per cent check		
					1T	2T	TL
Group A							
Cabbage	28	10	5	209.44	93.05	95.10	59.81
Tomato	18	13	7	149.94	93.17	53.20	58.20
Lettuce	34	15	12	68.73	97.30	42.99	61.11
Cauliflower	38	19	10	203.29	105.34	83.13	66.51
Beets	50	22	10	137.85	97.11	89.18	99.70
Group B							
Celery	36	30	21	328.11	96.52	54.12	62.81
Eggplant	20	15	9	83.89	114.78	75.12	66.21
Group C							
Beans	16	5	3	39.16	89.22	.....	39.74
Corn	16	5	4	84.76	122.27	.....	37.36
Melons	16	6	4	82.36	74.69	.....	33.68
Cucumbers	32	6	4	104.16	91.12	.....	45.91

* Number of plants in each treatment.

the age of the plants at the time of the late transplanting, the average weight of the check in grams, and the three transplanting comparisons expressed as a percentage of the green weight of the check, are given in table 2.

The vegetables used are divided into three groups. In group A are those crops which either are commonly transplanted or are thought of as easily surviving this operation. In group B are plants requiring more care in handling, and in group C are plants not successfully transplanted by usual methods. The average performances of the different groups are compared in table 3. The errors are those incidental to averaging and are not entirely fair to the data as a whole.

TABLE 3. Summary of the Results of Transplanting in Greenhouse Beds

Group	Age at last transplanting (weeks)	Transplanting treatment, as per cent green weight of check		
		1T	2T	TL
A	9	97.2 ± 1.4	65.5 ± 6.0	69.1 ± 5.2
B	15	105.6 ± 6.2	64.6 ± 7.0	64.5 ± 0.9
C	4	86.8 ± 9.9	.....	38.5 ± 3.9

A consideration of tables 2 and 3 shows that there was no significant effect from the first transplanting in any of the groups. The check in growth from two transplantings or from one late transplanting may be taken as significant, although the probability margins are narrow in most instances. Attention is directed to two indications given by this work. A single late transplanting was comparable in effect to two transplantings, when the last shift was made at the same time in both instances. Plants in group C were more injured than those in the other groups, although they were less than half as old and were somewhat smaller. This relation will be given further consideration under the effect of size of plant upon ability to withstand transplanting.

Most of these crops were harvested within a relatively short time after the late transplanting, so that equalizations which might have appeared later were not included. Of the tests listed in table 2, one on cauliflower and two on beets were allowed to mature in the greenhouse. The averages of these mature, and of the immature, crops in group A are given in table 4. These group-A plants, when allowed to continue growth, largely overcame the check caused by transplanting. This will be taken up again when considering the field work.

TABLE 4. PERSISTENCE OF TRANSPLANTING INJURY

	Number of tests	Transplanting treatment, as per cent green weight of check		
		1T	2T	TL
Group A, immature	7	98.2 ± 2.7	58.5 ± 4.9	58.1 ± 1.2
Group A, mature	3	99.2 ± 1.4	88.5 ± 0.6	89.7 ± 6.7
Gain with maturity	..	1.00 ± 3.0	30.0 ± 4.9	31.6 ± 6.8

Effects of transplanting upon root branching

One of the principal arguments that is advanced in favor of transplanting is that increased branching of the root system is induced by the root pruning. Twenty-five of the twenty-six growers listed in table 1 considered the root systems of transplanted plants "better" than those of plants not transplanted. The increased branching is marked and usually varies directly with the severity of the check to the plant.

An idea of the effect of transplanting upon the number of branches arising at or near the main stem is given in figures 2 to 6. In general, a slight increase in number of roots was not accompanied by a decreased spread, and the opposite was frequently true. Marked increases in branching resulted in a very considerable reduction in feeding area.

Effects of transplanting upon ratio of roots to tops

Several experiments were conducted to determine the effect of transplanting upon total root growth and upon the ratio between root and top weights. As will be shown more fully when considering root replacement, the ratio between roots and tops may fluctuate widely for a short period after transplanting but tends to come to an equilibrium which is dependent upon the balance between growth and food supply in the plant. The tendency of the transplanted plants to assume a normal proportion of roots is illustrated in table 5.

These plants had been grown under different moisture conditions before transplanting, and considerable differences in proportion of roots had been established, particularly in the cabbage. After transplanting, and with an optimum moisture supply, all plants returned rapidly to the value of the tender check plants.

That wide variations in the root and top ratio are possible with prolonged differences in treatment is well illustrated in table 6, which gives the root and top ratio of fruiting tomato plants grown with different moisture and nitrogen supplies.

TABLE 5. ROOT AND TOP RATIOS AFTER TRANSPLANTING

Crop	Weight of roots, as per cent of the green weight of tops		
	At time of transplanting	1 week after transplanting	2 weeks after transplanting
Tomato, tender plants	22.10	30.20	21.20
Tomato, hardened plants	26.70	34.80	23.00
Cabbage, tender plants	12.30	13.12	10.84
Cabbage, hardened plants	18.40	8.89	12.38

FIGURE 2. EFFECTS OF TRANSPLANTING UPON THE ROOT SYSTEM OF CAULIFLOWER
Left, check; center, once transplanted; right, twice transplanted. Photo taken as heads were forming

FIGURE 3. EFFECT OF ROOT PRUNING IN TRANSPLANTING UPON THE ROOT SYSTEM OF TOMATO
Left, check; center, once transplanted; right, twice transplanted

TABLE 6. EFFECT OF MOISTURE AND NITROGEN ON ROOT AND TOP RATIO IN THE TOMATO

Moisture	Nitrogen	Green weight of plants (grams)	Roots, as per cent of the green weight of tops
Optimum	Optimum	224	19.4 ± 0.9
Low	Optimum	137	31.1 ± 1.0
Optimum	Low	95	49.1 ± 3 2
Low	Low	73	55.4 ± 3.6

An increase of nearly 200 per cent in the root-top ratio accompanies the decreased growth under the less favorable conditions, and the increase is almost inversely proportional to the growth of the tops. These plants were grown in large boxes containing 100 pounds of sand, and the results are averages of five determinations.

When an attempt was made to obtain data on the effect of transplanting on root-top ratio, it was found that the confinement of the roots in 8-inch pots gave the increased branching usually associated with transplanting. Also, the root ratio was found to vary, not with the transplanting treatment, but with slight irregularities in the water supply immediately preceding the taking of the data. For this reason the data are not given, but they, as well as the results of several other experiments, support the general assumption that root and top ratio is a constantly changing balance dependent upon the relative supplies of water and salts to the top and of organic food to the roots. Only as it changes these and only for the duration of such changes does transplanting affect the ratio of roots to tops.

Relation of maturity of plant to effect of transplanting

It has been shown that the check from transplanting recorded in table 2 was largely due to the late transplanting. It may also be pointed out that, whereas the late transplanting was given at an average age of nine weeks in group A and resulted in a loss of 31 per cent, it was given at four weeks in group C and retarded the development of the plants 61.5

FIGURE 4. EFFECT OF TRANSPLANTING UPON ROOTS OF SNAP BEAN
Left, check; center, once transplanted at one week; right, once transplanted at three weeks

FIGURE 5. EFFECT OF TRANSPLANTING UPON TOP AND ROOT DEVELOPMENT OF CELERY
Right, once transplanted at four weeks; left, twice transplanted, at four and at eight weeks

per cent. The trend of the earlier work indicated that practically any vegetable could be transplanted with little injury in the earlier stages, but that there is a wide variation in the period during which the plants can be successfully moved.

A number of tests were carried out under the general conditions already outlined, to determine the relation between age of plant and effect of transplanting. All rows were seeded and thinned at the same time and in the same way. As the plants developed, those in successive rows were taken up with a small ball of earth and returned to the same position. Transplantings were given at intervals of one week, counting from date of seeding, and every third row was left as a check, without transplanting. In making the tables, progressive base values were calculated for each row from the nearest checks, and the observed weight of the plants was expressed as a percentage of this value.

FIGURE 6. EFFECTS OF TRANSPLANTING UPON THE FORMATION OF PRIMARY BRANCHES IN THE ROOT SYSTEM OF CABBAGE

Left, check; center, once transplanted at two weeks; right, twice transplanted, at two and at six weeks

TABLE 7. EFFECT OF AGE OF PLANT UPON INJURY FROM TRANSPLANTING

Transplanting treatments as per cent green weight of checks. Sixteen plants were used for each treatment in each test.

Crop	Number of tests	Age at harvest (weeks)	Age from seeding at time of transplanting (weeks)				
			1	2	3	4	6
Group A							
Cabbage	2	9	93.69	98.24	84.74	77.69	56.50
Tomato	2	8	100.24	72.30	67.10	69.36	46.23
Lettuce	1	8	97.96	78.73	76.97	46.30	61.46
Cauliflower	1	9	106.43	100.64	78.33	70.60	36.47
Average			99.58±1.63	87.48±4.72	76.79±2.58	65.99±4.59	50.17±3.74
Group C							
Cucumbers	2	6	91.12	74.95	70.71	45.91	
Melons	1	6	74.69	61.04	45.27	33.68	
Corn	2	5	122.27	60.25	38.74	37.36	
Average			96.03±9.43	65.41±3.23	51.57±6.58	38.98±2.46	

Some of the more easily transplanted crops and some not usually transplanted are compared in table 7, which shows the rapid divergence between the two groups with increasing age of the plants.

Increasing injury is apparent in both groups under the conditions of the experiments, but the rate of increase is nearly twice as great with group C as with group A. Between one and four weeks, the amount of injury increased 33.6 per cent in group A and 57.1 per cent in group C. It is significant that transplanting one week after seeding gives, within the limits of error, the same results in both cases.

Relation of rate of growth to effect of transplanting

The second column of table 7 gives the age of the plants at the time of harvest and represents the stage at which crowding sufficient to have affected the value of the results was threatened. The group-A crops are seen to have required nearly 50 per cent more time than those of group C to reach the same stage. That this factor of rate of growth is important in determining the amount of injury from transplanting may be seen by comparing the effect upon the same crop under different conditions. In table 8 the results obtained with a slow-growing crop of cabbage produced in midwinter are compared with the data given in table 7. Two slow-growing crops, celery and peppers, are included to

TABLE 8. EFFECT OF RATE OF GROWTH UPON INJURY FROM TRANSPLANTING

Transplanting treatments as per cent green weight of checks

Crop	Age at harvest (weeks)	Average weight of check plants (grams)	Age at time of transplanting (weeks)				
			2	4	6	8	10
Cabbage, winter	16	85.82	106.97	97.17	81.21	95.89	87.34
Cabbage, spring	9	145.50	98.24	77.69	56.50	.....	.....
Average, group A (table 7)	8.5	.....	87.48	65.99	50.17	.....	.....
Celery	16	65.17	.....	92.72	99.72	88.93	59.48
Peppers	10	23.75	132.32	131.98	85.42	44.47	.....

show that, although these plants are less resistant to unfavorable conditions of transplanting than cabbage and tomatoes, they show little injury when young because their naturally slow growth does not create a wide gap between the checks and the plants whose top growth has been temporarily stopped by transplanting.

An observation which supports the view of the importance of rate of growth is illustrated by the data for lettuce in table 7, where the plants transplanted at 4 weeks are 46 per cent of the check, and those at 6 weeks 61 per cent. In several instances the larger plants seemed to have been less injured in terms of the check than the medium sized, and the difference was apparently correlated with the increased rate of growth through the medium range. This does not mean that plants should be left until large before transplanting, because, as will be shown later, the decreased rate of growth of the larger plants is accompanied by a decreased rate of root replacement in the transplanted lots. Rate of root replacement is always an important factor and becomes dominant in older plants. Maximum injury from transplanting is associated with a rapid rate of growth and a slow root replacement which increase the check in terms of time. Corn is an example of a crop very seriously injured by transplanting for these two reasons.

Transplanting tests in the field

Part of the value of a study of transplanting is its direct application to the problem of plant-growing methods. Shall the gardener grow his plants in pots at large expense to avoid transplanting? or is the check of such a nature that it will be largely overcome in the course of the season and may therefore be disregarded? or is a compromise likely to prove most satisfactory? Field results may thus be the more interesting for the gardener, although the lack of controlled conditions and the sharp check to the growth of all lots at the time of moving the plants to the field may make such results less indicative of the actual effect of transplanting than work in the greenhouse. The slow growth and retarded maturity will also tend to level small differences in size when no complicating factors, such as are encountered in stunting, are involved.

Growing the plants

During the seasons of 1922, 1923, and 1924, field tests of the effect of early transplantings given in the greenhouse were made with tomatoes, cabbage, and celery. The details varied somewhat with the crop and the year, but in every instance the young cabbage and tomato plants in the house were spaced 4 by 4 inches from the start, and the celery 2 by 2 inches. The number of transplantings listed was given previous to moving to the field, so that plants grown in flats or ground beds received an additional disturbance of a severe nature at the time of setting in the field. With all treatments the seed was sown in place and was then thinned, or thinned and transplanted. The flats contained 2 to $2\frac{1}{2}$ inches of soil and the paper pots $2\frac{1}{2}$ to 3 inches. Especial care was given in watering to maintain uniform growth in all lots. The flats were placed on platforms to prevent any roots getting into the greenhouse soil. They were turned at intervals, and the pots or parts of flats were watered indi-

vidually as they showed need of water. The plants were neither forced during growth nor hardened at the end, but made a thrifty though somewhat slow growth throughout.

Interpretation of the data

In interpreting the field work it is necessary to consider the points in which the conditions of these experiments differed from those conducted in the house. The sharp check to all treatments when moved to the field and the slow development afterwards have been mentioned as factors tending to equalize small differences in size of plants. Another difficulty which cannot be eliminated when setting early plants to the field is shown in figures 7 and 8. When the plants are grown wholly

FIGURE 7. CABBAGE PLANTS FROM THE BED, 1922

Left, check; center, *1T*; right, *2T*. The plants below show the tendency of the respective treatments to retain balls of earth with their roots; those above show root development

FIGURE 8. CABBAGE PLANTS GROWN IN PAPER POTS

Left, check; center *1T*; right, *2T*. These plants show increased branching of roots from confinement in pots, as well as from transplanting. Compare the root systems of the check plants with those of the checks from ground beds in figure 7

in ground beds or deep benches, they develop normal root systems but will be very seriously disturbed when moved to the field. As has been shown, one transplanting of large plants may have the same effect as two or three transplantings when smaller, so that differences induced by seedbed treatment, especially if such differences are matters of size only, may disappear when the plants are set in the field. On the other hand, plants grown in pots show an abnormal amount of branching (figure 8),

so that their development cannot be considered to be the same as that of plants grown without restriction of the roots.

In the field tests, four repetitions of ten or more plants were used for each treatment. End plants and outside rows were invariably discarded. Tomato plants were set 4 by 4 feet; cabbage 18 by 30 inches, and celery 6 by 36 inches. Shallow cultivation was given during the early part of the season and weeds were kept down by hand hoeing after cultivation ceased.

Because climatic conditions were unusually variable, no attempt has been made to average the data of the three seasons, but they are given separately for better comparison.

Field work with cabbage

The results obtained with cabbage in 1922 are given in table 9. The size of these plants at the time of taking to the field is shown in figures 7 and 8. The increased amount of soil adhering to the transplanted plants from the bed is indicated in figure 7. It was possible to transfer a good ball of earth with the twice-transplanted plants, while the roots of the check plants were practically bare.

TABLE 9. EFFECT OF TRANSPLANTING YOUNG CABBAGE PLANTS IN THE GREENHOUSE UPON DEVELOPMENT IN THE FIELD, 1922 *

Plants grown in	Treatment	Per cent heading	Weight early, in tons per acre	Per cent total weight cut as early	Total yield marketable heads, in tons per acre
Paper pots	Check	98.01	6.44 ± 1.03	51.03	12.62 ± 1.11
	1T	96.15	4.35 ± 0.91	35.22	12.35 ± 1.13
	2T	96.15	4.73 ± 0.75	37.07	12.76 ± 1.43
Average		96.77	5.17 ± 0.52	41.11	12.58 ± 0.71
Ground beds	Check	88.46	2.23 ± 0.38	18.37	12.14 ± 1.65
	1T	84.61	2.30 ± 0.59	21.20	10.85 ± 1.40
	2T	71.15	1.35 ± 0.59	19.37	6.97 ± 0.88
Average		81.41	1.96 ± 0.31	19.65	9.99 ± 0.78

* Copenhagen Market, Harris; seed sown March 27, first transplanting April 11, second transplanting May 4, set to field May 18; first cutting (early) July 21, last cutting July 31; 52 plants in each treatment; weather conditions very favorable.

No indisputable odds are given in table 9, but the data indicate that early treatments in the greenhouse had no effect on either earliness or total yield. Transplanting after the plants were large, and particularly a severe root pruning at the time of setting in the field, retarded the

development of the heads; and the combination of these treatments in the *2T* plants from the bed gave a reduction of 5 tons an acre in total yield with odds of about 15 to 1. This occurred in spite of the "better" root system of the *2T* plants as shown in figure 7 and the fact that more soil was retained on the roots of this lot.

The results of 1923 are given in table 10. The same test was repeated, except that the second lot of plants was grown in flats instead of in ground beds. An attempt was made to compare the effects of the check in growth from transplanting with plants started two weeks later, but the weather was so dry that the late plants failed to form marketable heads and only about one-third headed at all. The results indicated a difference of considerably less than two weeks between the check and the transplanted plants.

TABLE 10. Effect of Transplantings Given in the Greenhouse upon Performance of Cabbage in the Field, 1923 *

Plants grown in	Treatment	Per cent heading	Weight early, in tons per acre	Per cent total weight cut as early	Total yield marketable heads, in tons per acre
Paper pots	Check	80.0	4.54 ± 0.79	83.97	5.22 ± 0.68
	1T	87.5	4.40 ± 0.58	80.29	5.48 ± 0.54
	2T	75.0	3.11 ± 0.86	71.66	4.34 ± 0.69
Average		80.83	4.02 ± 0.43	79.64	5.01 ± 0.37
Flats	Check	75.0	3.30 ± 0.85	73.50	4.49 ± 0.73
	1T	70.0	3.78 ± 0.75	82.35	4.59 ± 0.84
	2T	70.0	3.19 ± 0.52	78.19	4.08 ± 0.41
Average		71.67	3.42 ± 0.41	78.01	4.39 ± 0.40

* Copenhagen Market, Harris, seed sown February 25, first transplanting March 14, second transplanting April 11; set to field April 25; early cuttings July 20 and August 1; final cutting August 14; 40 plants in four repetitions for each treatment; weather very dry throughout the season.

The results of 1923 differ from those of 1922 in showing relatively better yields from the plants grown in flats than was obtained from those grown in beds. This would be expected from the increased amount of roots and soil than can be retained with the plants from the flats. All of the yields were low in 1923 because of the prevailing dry weather, and this influence, together with the natural tendency of initial differences in size to disappear with growth, has almost entirely eliminated the effects of the transplanting treatments.

For the 1924 test with cabbage, the comparisons were limited to paper pots but the number of repetitions was increased. The results, given

in table 11, correspond to the other data in showing little effect from transplanting young plants. Only one significant difference is shown, the reduced percentage of early heads on the *1T* plants. The cause of this reduction is not readily apparent but probably arose while holding the plants for favorable weather for field setting in a late season.

TABLE 11. EFFECT OF TRANSPLANTINGS GIVEN IN THE GREENHOUSE UPON THE DEVELOPMENT OF CABBAGE IN THE FIELD, 1924 *

Treatment (all plants in 4-inch paper pots)	Per cent heading	Weight early, in tons per acre	Per cent of total cut as early	Total yield marketable heads, in tons per acre
Check	98.18	3.121 ± 0.190	40.52	7.703 ± 0.286
Transplanted once	94.55	1.808 ± 0.174	23.41	7.724 ± 0.523
Transplanted twice	98.18	3.048 ± 0.443	38.83	7.850 ± 0.367

* Seed was Harris' Wakefield, sown March 8, transplanted in house on March 17 and April 17, set to field April 28. Early cuttings were taken July 6 and 9, late cuttings July 17 and August 6.

Field work with celery

The work with celery paralleled rather closely that with cabbage. In 1922, plants grown 2 by 2 inches in ground beds in the greenhouse were compared with plants from 2-inch paper pots. Only one transplanting was given. In 1923, the regular comparisons, check, *1T*, and *2T*, were made in 2-inch paper pots and in flats. These plants were grown under irrigation in the field, and part of the low value in the 1923 check in pots was due to a poor nozzle over one of the check rows.

TABLE 12. EFFECT OF TRANSPLANTING YOUNG CELERY PLANTS UPON DEVELOPMENT IN FIELD, 1922 AND 1923

Plants grown in	Treatment	1922 test, averages of 180 plants	1923 test, averages of 52 plants
2-inch pots	Check	31.00 ± 0.84	45.17 ± 2.20
	1T	30.63 ± 1.26	48.26 ± 2.47
	2T	.....	54.46 ± 3.11
Average	.....	30.81 ± 0.76	49.30 ± 1.51
Beds, 1922; flats, 1923	Check	31.00 ± 2.06	57.79 ± 2.58
	1T	31.50 ± 1.54	56.15 ± 2.61
	2T	.....	58.22 ± 2.40
Average	.....	31.25 ± 1.29	57.39 ± 1.46

The difference between the check and the *2T* potted plants in 1923 is just above the minimum odds of 30 to 1, but, as pointed out, part of this difference was due to uneven watering. The 1922 results, which are perhaps the more reliable of the two, show no variation in performance with the various treatments. This may be demonstrated by considering the four averages as being of the same treatment and determining the *PE* of the average of the four figures. This is found to be ±0.28 as compared to a low value of ±0.84 and a high of ±2.06 for the individual means. These figures indicate several times the variation in repetitions of the same treatment that occurred in the means of the different treatments.

Field work with tomatoes

Tomatoes are well adapted to experimental work of this type and were used for a number of experiments. In 1922, in addition to a comparison of transplanting with pot- and bed-grown plants, one experiment was run in which the seed was sown directly in the field and later thinned and transplanted. The same experiment was started with cabbage, but the plants were destroyed by rot. In 1923 tomato plants of two ages were used and, probably because of the lateness of the season, the younger plants gave both earlier and heavier yields. The 1924 comparisons were entirely with pot-grown plants. As with cabbage, the results of different years are not averaged.

The data from the 1922 tests are given in table 13. The check and the once-transplanted plants from the bed were badly drawn, being as

TABLE 13. Effects of Transplanting Young Plants upon Development of Tomatoes in the Field, 1922 *

Plants grown in	Treatment	Average weight fruits (grams)	Early, in tons per acre	Early, in per cent total	Marketable, as per cent total	Total yield, in tons per acre
4-inch paper pots.	Check..	92.13	2.68 ± .37	25.10	79.03	10.69 ± 0.66
	1T.....	109.05	3.77 ± .37	30.57	78.49	12.33 ± 1.32
	2T.....	88.00	2.31 ± .13	26.18	70.41	8.82 ± 0.51
Average.....	.....	96.39	2.92 ± .18	27.28	75.98	10.61 ± 0.52
Groundbeds.....	Check..	90.08	1.30 ± .17	18.48	75.95	7.03 ± 0.39
	1T.....	88.13	2.01 ± .14	22.70	75.43	8.83 ± 0.18
	2T.....	93.08	2.06 ± .16	23.54	78.32	8.73 ± 0.32
Average.....	.....	90.43	1.79 ± .09	21.57	76.57	8.20 ± 0.13

* Bonny Best, Harris; seed sown March 27; first transplanting April 11; second May 4; set to field May 26; early fruit July 15 to August 25; final picking September 16; total of 40 plants in 4 repetitions; weather conditions good.

much as two feet long and very succulent, even though the deep greenhouse soil in which they grew had not been watered for several weeks before they were set in the field. It was impossible to obtain any soil with these or more than the vestiges of a root system, so that their chances of survival did not appear promising. Some of them lost part of their tops through sunburn of the stems and some were broken in cultivating, but the majority developed surprisingly well.

Two comparisons give significant results in this test. The transplanted plants from the bed were better than the check plants, with odds in the neighborhood of 30 to 1; and the average of the potted plants is above that of the plants from the bed on both earliness and total yield by odds of several hundred to one. The difference in favor of the transplanted plants from beds was small and was at least partially due to mechanical

TABLE 14. EFFECTS OF TRANSPLANTING YOUNG PLANTS UPON DEVELOPMENT OF TOMATOES IN THE FIELD, 1923 *

Plants	Treatment	Average weight of fruits (grams)	Early, in tons per acre	Early, as per cent total	Marketable, as per cent of total	Total yield, in tons per acre
Large, in 4-inch paper pots...	Check...	82.55	3.37 ± .10	26.25	71.57	12.84 ± 0.32
	1T.....	84.89	3.28 ± .43	25.21	71.64	13.01 ± 0.32
	2T.....	80.12	3.62 ± .24	27.14	71.29	13.34 ± 0.64
Average...	.....	82.52	3.42 ± .17	26.20	71.50	13.06 ± 0.26
Large, in flats..	Check...	77.77	2.25 ± .23	22.48	66.43	10.01 ± 0.52
	1T.....	80.48	2.63 ± .45	21.26	68.71	12.37 ± 1.18
	2T.....	80.23	2.44 ± .18	21.37	71.02	11.42 ± 0.21
Average...	.....	79.49	2.44 ± .18	21.70	68.72	11.27 ± 0.44
Small, in 4-inch paper pots...	Check...	85.08	3.82 ± .10	28.11	73.88	13.59 ± 0.93
	1T.....	81.28	3.93 ± .07	28.36	72.29	13.86 ± 0.63
	2T.....	86.61	4.09 ± .25	29.90	69.52	13.68 ± 1.03
Average...	.....	84.32	3.95 ± .09	28.79	71.90	13.71 ± 0.51
Small, in flats..	Check...	74.78	3.35 ± .11	26.99	68.40	12.41 ± 0.20
	1T.....	76.32	2.69 ± .10	25.92	66.96	10.38 ± 0.18
	2T.....	78.10	3.28 ± .05	27.04	68.43	12.13 ± 0.53
Average...	.....	76.40	3.11 ± .05	26.65	67.93	11.64 ± 0.20

* Bonny Best, Harris; seed for large plants sown March 10, small, March 24; first transplanting March 24 and April 7; second transplanting April 16 and April 23; set in field May 25; early fruit July 9 to August 20; cleanup September 21.

injury in the field, which resulted from the badly drawn condition of the untransplanted plants. The loss in earliness in the plants from the bed compared with the average of those in 4-inch pots was 39 per cent, while the loss in total yield was only 23 per cent, which shows again the tendency of the transplanted plants to recover with time.

The work of 1923 carries out the conclusions which must be drawn from the 1922 data, which are that transplanting treatments given previously to shifting to the field are capable of being so masked by the late treatments as to be indistinguishable in the final results, but that the severity of root pruning at the time of setting in the field may materially affect the earliness and the yield of the crop. The plants are larger at this time and therefore supposedly more susceptible to injury. In addition, any differences in size which may be induced will not be leveled out as they will in the greenhouse where the plants must be held back until they can be set in the field. During this period of slow growth the larger, untransplanted plants are checked more than the transplanted lots, intentionally or otherwise, and differences in size which might make a small showing in the field are lost.

TABLE 15. Effect of Transplantings Given in the House upon Development of Tomatoes in the Field, 1924 *

Treatment (all plants in 4 inch paper pots)	Average weight of fruits (grams)	Early, in tons per acre	Early, in per cent total yield	Grade 1 as per-centage of market-able	Total yield marketable fruit, in tons per acre
Check	119.43	1.699 ± 0.056	16.11	70.26	10.549 ± 0.510
Transplanted once	118.61	2.534 ± 0.151	23.05	70.48	10.992 ± 0.601
Transplanted twice	117.04	2.367 ± 0.148	22.91	69.92	10.331 ± 0.678

* Seed was Harris' Bonny Best, sown March 22; transplanted in house April 7 and May 1, set to field May 28. The first picking was made on July 22, and all pickings of July and August are included in early fruit; final picking September 25.

In 1924, plants were grown only in 4-inch paper pots with the usual transplanting treatments. A study of the data in table 15 shows only one significant difference, that the check plants produced less early fruit than did those that were transplanted. These plants were started with the expectation that they would be set in the field about May 20, but the late season made it necessary to hold them another week in a greenhouse maintained at the proper temperature for cucumbers. The result was that the control plants were slightly stunted and the blossoms of the first cluster were largely lost. The transplanted plants were less advanced and suffered less. This reemphasizes a point which has been made before, that the growth of young plants may be arrested without

serious injury, but that the effect of equivalent checking increases with the maturity of the plants.

The advantages of pots are emphasized in table 16, which brings together the data comparing flats with paper pots.

TABLE 16. EFFECT OF THE USE OF PAPER POTS IN GROWING TOMATO PLANTS

Plants grown in:	Early, in tons per acre	Gain for pots (per cent)	Odds that difference is significant	Total yield, in tons per acre	Gain for pots (per cent)	Odds of significance
Paper pots, 1922	2.92 ± .18	63.0	.....	10.61 ± .52	29.5	.....
Flats, 1922	1.79 ± .09			8.20 ± .18		
Difference	1.13 ± .20	....	10,000 to 1	2.41 ± .55	....	332:1
Large plants, 1923, paper pots	3.42 ± .17	40.1	.....	13.06 ± .26	15.8	.....
Flats	2.44 ± .18			11.27 ± .44		
Difference	0.98 ± .25	....	116 to 1	1.79 ± .51	....	54:1
Small plants, 1923, paper pots	3.95 ± .09	27.0	.....	13.71 ± .51	17.7	.....
Flats	3.11 ± .05	....	.....	11.64 ± .20	....	.....
Difference	0.84 ± .10	....	1,000,000,000 to 1	2.07 ± .55	....	95:1

In 1922, besides the plants from the house, tomato seed was sown in place in the field and was then given the four standard transplanting treatments. The lower end of the block was so badly washed by a hard, driving rain in June as to make it necessary to discard the results from two of the four repetitions. Of the two remaining plots, the yield of one

TABLE 17. TRANSPLANTING TESTS WITH TOMATO PLANTS GROWN WHOLLY IN THE FIELD, 1922

Treatment	Average weight of fruit (grams)	Ripe fruit, in tons per acre	Early, as per cent total	Marketable, as per cent total	Total yield, in tons per acre, ripe and green
Check	72.71	1.93 ± .40	45.33	65.55	4.25 ± .63
IT	76.02	2.41 ± .21	53.21	70.18	4.53 ± .53
2T	61.60	0.73 ± .05	24.71	58.82	2.97 ± .52
TL	64.00	1.00 ± .22	31.98	58.54	3.11 ± .32

was uniformly higher than that of the other in all treatments and the result in a high probable error. For this reason no certain differences can be distinguished in the total yield of the treatments, which includes green fruit remaining on the vines October 2. The large differences in early or ripened fruit may be shown to be significant and demonstrate the effectiveness of transplanting in retarding maturity. In a larger experiment, where the error would be smaller, one would expect a significant difference in total yield in an experiment of this type, since not all of the crop was matured and earliness should, under these conditions, correspond with increased yields.

Field work with beans

One small test was made with beans in 1922, the only field work with group-C plants. Six lots of seventy plants each were used, of which two were left as checks, two transplanted before the seed leaves were fully expanded, and two at about three weeks. The results are given in table 18.

TABLE 18. Effects of Transplanting Beans

Treatment	Weight of pods from 36-foot row (pounds)	Weight of vines (pounds)
Check	8.5	10.7
Transplanted small	6.2	7.4
Transplanted large	3.5	4.4

No difficulty was experienced in getting the transplanted plants to live, but those transplanted when large were less than half the size of the checks and produced only about one-third as large a crop. Apparently permanent changes, either structural or chemical, had been induced during the long time that the plants stood before resuming growth.

Effect of the larger, more branched root systems resulting from transplanting, upon performance in the field

As already mentioned, the production of a "better" root system is frequently advanced as a strong argument in favor of transplanting. In order to test this, a block of plants was started in the greenhouse bed in the spring of 1923. As the plants were taken up for the field, every third plant was retained for measurements of root and top growth. The development of the plants at this time is indicated in figure 9. The weight of the roots was roughly the same for all treatments but the tops varied from 18 to 60 grams, so that the comparison is really one between the

FIGURE 9. TOMATO PLANTS FOR FIELD EXPERIMENT ON RELATION OF ROOT AND TOP RATIO TO RECOVERY FROM TRANSPLANTING

Plants at left transplanted once at two weeks; at right, transplanted twice, at two and at six weeks

importance of top and roots in the reestablishment of the plant after transplanting. The average weight of the plants set to the field, their root-top ratio, $\frac{\text{roots}}{\text{tops}} \times 100$, and their performance in the field are given in table 19.

The errors take care of the differences in total yield and give low odds on the variations in earliness. Certainly the larger proportion of roots does not appear to be beneficial, and there are indications, if not proof, that the larger plants will bear more early fruit although perhaps no larger total if the season is sufficiently long.

TABLE 19. The Relation of Size of Tops and Proportion of Roots to Transplanting Injury

Treatment	Average weight of plants (grams)	Roots, as per cent of tops	Early fruit, in tons per acre	Total yield, in tons per acre
Check	61.61	3.21	3.45 ± 0.26	13.31 ± 0.43
1T	49.24	4.08	3.97 ± 0.19	13.87 ± 0.46
2T	20.34	8.19	2.71 ± 0.22	11.59 ± 0.41
TL	18.75	8.18	3.03 ± 0.13	12.43 ± 0.49

Effects of wilting and slow drying with transplanting

Plants that are transplanted under unfavorable conditions of humidity and soil moisture are subject to a rapid wilting which may prove fatal. The same wilting may result from poor protection of the plants after digging. Those plants which escape death by wilting will be subjected to a slower drying until the new root system becomes established. The severity of this drying will vary with the soil moisture and the air conditions. As a rough test of the resistance to these two types of drying, an experiment was run in which one lot of plants was wilted for six hours before transplanting, another was transplanted directly into moist soil and left without water for fourteen days, and a third was transplanted and watered as a control. Wilting periods of fifteen minutes to six hours and drying periods of two to fourteen days were used, but only the extremes are given since the shorter periods had little effect.

The plants to be wilted were taken up in the usual manner and the soil carefully removed. The roots were then enclosed in chambers lined with moist blotting paper and the tops exposed to the air of the room at 23°C. and 35 per cent relative humidity. The purpose of the chambers was to prevent injury to the roots by direct drying. Apparently such injury was not entirely prevented with the small lettuce plants and is partly responsible for the low resistance to wilting shown by these lots. The small plants were in the two-week stage and the large in the six-week stage or slightly larger. One flat of twenty-four small or fifteen large plants was used in each lot. The check and the wilted plants were watered from the first. The plants receiving the drying treatments were watered after the fourteenth day until they were taken up for measurement on the twenty-eighth day. Weights were obtained on all lots, but, since any comparison by weights indicates the rapidity of growth of the check rather than of the treatment, they are not given.

The percentage of plants alive after four weeks of the drying treatment is given in table 20.

TABLE 20. A COMPARISON OF THE RESISTANCE OF SOME VEGETABLE PLANTS TO RAPID WILTING AND TO SLOW DRYING AFTER BEING TRANSPLANTED INTO MOIST SOIL

Crop	Size and condition	Per cent surviving 6-hour wilting	Per cent surviving 14-day drying in soil
Group A			
Cabbage	Large, hardened	100.0	100.0
Cabbage	Large, tender	100.0	100.0
Cabbage	Small, tender	100.0	100.0
Tomato	Large, hardened	100.0	66.7
Tomato	Large, tender	86.7	60.0
Tomato	Small, tender	91.7	91.7
Lettuce	Large, tender	80.0	66.7
Lettuce	Small, tender	17.4*	95.7
Lettuce	Small, hardened	13.0*	73.9
Group B			
Celery	Small, tender	75.0	16.7
Salsify	Small, tender	95.9	66.7
Group C			
Lima bean	Large, tender	100.0	0
Muskmelon	Small, tender	54.2	0
Watermelon	Small, tender	66.7	0
Average, group A		76.5 ± 7.98	83.9 ± 3.98
Average, group B		85.4 ± 7.01	41.7 ± 16.85
Average, group C		73.6 ± 10.10	0.0 ± 0

* The low resistence of these plants was probably due to the exposure and serious drying of the roots. The apparatus was not well adapted to such small, short-stemmed plants.

Because of the small number of crops used, the probable error for the average of the two figures in the second column, group B of table 20, is too large to make it possible to consider this group. The other data, however, are suggestive as indicating that resistance to transplanting is not so much correlated with resistance to rapid wilting as with the ability to survive more prolonged and less rigorous treatment. The writer was inclined at first to consider such differences as are shown here to be explainable on the basis of a gradual adjustment, such as hardening, which is more effective in the group-A plants. In view of later work it seems probable that the differences can be more satisfactorily explained by rate of root replacement. The group-A plants rapidly developed a new root system and were able to maintain life in the drying soil. Such a view is supported by the absence of variation between the hardened and the tender plants used in the experiment and by the decreased loss in the small lettuce and tomato plants which would produce new roots more rapidly than the larger plants.

THE RELATION OF HARDENING, TRANSPIRATION, AND OTHER PROPERTIES OF THE TOP TO TRANSPLANTING

Sap concentration in hardened and in tender vegetable plants

All previous theories and practices pointed to a relation between hardening and transplanting similar to the relation between hardening and frost resistance demonstrated by Harvey (1918) and Rosa (1921). It does not follow that the same sort of hardening process is concerned, since tomatoes and other plants which are not frost resistant are classed as easily transplanted, but it still seemed possible that changes which would reduce the transpiration and increase the water-retaining power or the carbohydrate reserve of the plant cells might be a factor in transplanting. Two tests of hardening adjustments were used, the freezing point of the cell sap and imbibition by the dried tissue.

In carrying out the freezing-point work it was not expected that the direct decrease in depression with hardening would be of any significance beyond indicating the relative extent of changes associated with an increase in the solute content of the sap. The maximum recorded increase in depression represents a variation in molar concentration of only about

FIGURE 10. TOMATO PLANTS IN POTOMETERS, AS USED FOR TRANSPIRATION AND ROOT-REPLACEMENT EXPERIMENTS

Plants at left, tender, grown with optimum moisture. Plants at right, hardened by reducing moisture. This shows the size of the plants and the methods of sealing and of watering

3/10 N, and most of the changes were of the order of N/10 or less. The direct effect of such a difference in reducing the evaporation from the leaf could scarcely be measured, and it is only as they indicate protoplasmic readjustments that freezing-point measurements can be of any value in this type of work.

The material used for this experiment was six- to eight-week old plants grown in flats. One lot of fifty plants had been kept dry for two weeks previous to the test and another held at optimum moisture. The dry plants had been at the wilting point for several days immediately preceding the thorough watering which was given the evening before the samples were collected. Collections were made between 8 and 9 a. m. The samples, which consisted of leaves from different parts of ten or more plants, were placed in 3-cm tubes and immediately corked, sealed with paraffin, and placed in a salt and ice mixture where they remained until used, but not less than two hours. The tubes were then washed to remove the salt, and dried. The frozen material was ground in a mortar to a fine pulp. Duplicate 3-cc samples were taken and their freezing points determined directly by means of a Beckman thermometer in a freezing bath held at $-9°$ C. $\pm$ 1°. Knudson (1921) has shown that the freezing point of expressed sap varies with the temperature of freezing and with the amount of pressure used in extraction. The use of the pulp without extraction was designed to eliminate these errors. Preliminary experiments indicated that the probable error of a single determination on tender material was about $\pm$ 0.005, or within the error of reading. The more thoroughly hardened plants gave less reliable results, probably because of the small amount of free water present, and gave a probable error of nearly $\pm$ 0.01°. Comparable extraction of such material would, however, have been very difficult.

The depression of the tender plants in the different groups, together with the observed increase in depression with hardening, is listed in table 21.

TABLE 21. FREEZING-POINT DEPRESSION OF THE TISSUES OF HARDENED AND TENDER VEGETABLE PLANTS

Vegetable	Depression, in degrees C.		Additional depression with hardening, in degrees C.
	Tender	Hardened	
Group A			
Cabbage, a	0.708	0.929	0.221
Cabbage, b	0.799	1.165	0.366
Tomatoes, a	0.593	0.725	0.132
Tomatoes, b	0.661	0.882	0.221
G. R. lettuce	0.543	0.789	0.246
Hanson lettuce	0.546	0.738	0.192

TABLE 21 (*concluded*)

Vegetables	Depression, in degrees C.		Additional depression with hardening, in degrees C.
	Tender	Hardened	
Group A (continued)			
B. S. S. lettuce	0.581	0.867	0.286
Beet	0.741	1.042	0.301
Cauliflower	0.743	1.066	0.323
Group B			
Pepper	0.716	0.910	0.194
Eggplant	0.627	1.135	0.508
Celery	1.065	1.244	0.179
Onion	0.686	0.854	0.168
Salsify	0.823	0.931	0.108
Group C			
Turnip	0.745	0.908	0.163
Watermelon	0.692	0.860	0.168
Muskmelon	0.615	0.743	0.128
Cucumber, a	0.693	0.775	0.082
Cucumber, b	0.602	0.683	0.081
Corn	0.593	0.683	0.090
Peas	0.791	1.068	0.277
Lima beans	0.787	0.997	0.210
Snap beans, a	0.640	0.849	0.209
Snap beans, b	0.736	0.870	0.134

A careful study of table 21 will show that there is not a good correlation between either the normal depression or the additional depression induced by hardening, and the ability of the plants to withstand transplanting. The averages of the groups in table 21, together with the probable error of the mean, and the odds that the figures representing difference in depression are significant, are given in table 22.

TABLE 22. Summary: Freezing-Point Depression of the Tissues of Hardened and of Tender Vegetable Plants

Average	Tender plants	Difference between hardened and tender	Odds that difference is smaller than that of group A
Group A	.657° ± .022°	.254° ± .016°	
Group B	.743° ± .099°	.231° ± .048°	<1 to 1
Group C	.689° ± .016°	.154° ± .013°	1050 to 1

With the exception of one low value for tomatoes and the high difference for peas, the figures for group C lie wholly below those of group A and are safely significant. Just what they signify is, however, not so easily determined. With the exception of peas the crops of group C are not frost resistant, but neither are peppers and eggplant in group B nor tomatoes in group A. Also, when we consider individual crops the correlation between depression adjustment and ease of transplanting is not always borne out. This is indicated by the uniformly high values for the legumes in group C, crops that are notoriously difficult to transplant. In some work which will be given later, cucumbers were found not to accumulate sugars upon hardening or after transplanting. If it were shown that a larger part of the increase in depression in group A was due to sugars or to other food material, we might consider the phenomena indicative of nutritional changes which would favor the rapid development of new roots. Without additional data, however, we can do little more than speculate on the possibilities.

Imbibition of water by the dried tissue of hardened and tender vegetable plants

The work of MacDougal (1916), of Rosa (1921), and of others, on the formation of pentosans and similar colloidal substances in response to deficient moisture and other hardening treatments, suggested that the most important changes concerned in hardening might be in the colloidal substances and so not measured by freezing-point determinations. Benedict (1915) used the swelling of dried powdered leaves as a measure of colloidal content. Several modifications of his method were tried. It was found that decantation could not be depended upon for removal of the surplus water because of the variation in capillarity with the fineness of the material. Some samples would readily crumble to dust while others were very resistant to powdering when air dry, and these differences affected the amount of free water retained by the sample. When whole plants were placed between moist blotting paper the water appeared on the leaves in drops, either through condensation or through guttation from the swelling tissue. It was also difficult to obtain uniform exposure to moisture and a uniform rate of absorption under these conditions. The method which appeared most promising employed the centrifuge for removing free water from the swollen sample.

The plants used in the freezing-point work were cut immediately after collecting samples for that experiment, and 50- to 100-gram lots were dried over steam pipes at 60° C. The dry material was powdered, weighed into covered dishes, and autoclaved while dry at 10 pounds pressure for thirty minutes. An amount of sterile water equal to the original weight of the sample was added and the experiment allowed to stand for forty-eight hours. To obtain readings, the wet leaves were filtered on cloths and centrifuged at 2500 r. p. m. for five minutes to remove

free water. Cloth and pulp were then quickly weighed with protection from evaporation, the pulp thrown out, and the wet cloth reweighed immediately. The difference less the original weight of the sample is the amount of water absorbed.

The total imbibition of the material from the tender plants, as a percentage of its dry weight, and the difference between the swelling of the tender and of the hardened samples are given in table 23. A negative difference indicates that the hardened sample imbibed less than the tender.

TABLE 23. Imbibition of Water by the Dried Tissue of Hardened and Tender Vegetable Plants

Crop	Swelling of tender, per cent dry weight	Difference, hardened and tender, per cent dry weight
Group A		
Cabbage	79.3	+ 5.2
Tomato	60.5	— 8.1
Lettuce	68.9	+26.4
Cauliflower	52.6	+ 0.7
Beet	42.9	+ 0.9
Group B		
Pepper	101.4	+ 6.2
Eggplant	97.4	+ 0.9
Celery	84.6	—18.5
Onion	61.0	—20.3
Salsify	78.8	— 4.0
Group C		
Turnip	45.5	— 4.1
Watermelon	64.6	—10.2
Muskmelon	98.4	— 9.9
Cucumber	68.4	— 3.9
Corn	108.0	— 6.0
Peas	81.9	— 9.5
Beans	108.0	—10.9
Limas	77.2	— 8.7
Average A	60.84	+ 5.0 ± 3.9
Average B	84.64	— 7.1 ± 3.5
Average C	81.50	— 7.9 ± 0.7

The magnitude of the probable errors of the average differences shows at a glance that the figures cannot be taken as significant. The odds that the difference between groups A and C is significant are only 22 to 1, compared with an allowable minimum of 30 to 1. This does not mean that there is no correlation between hardening and collodial content but

that such differences, if occurring, cannot be measured by this method. The negative differences indicate the accumulation of substances which have a lower absorbing power than the normal cell constituents. Such accumulations mask colloidal differences. There is also the difficulty of

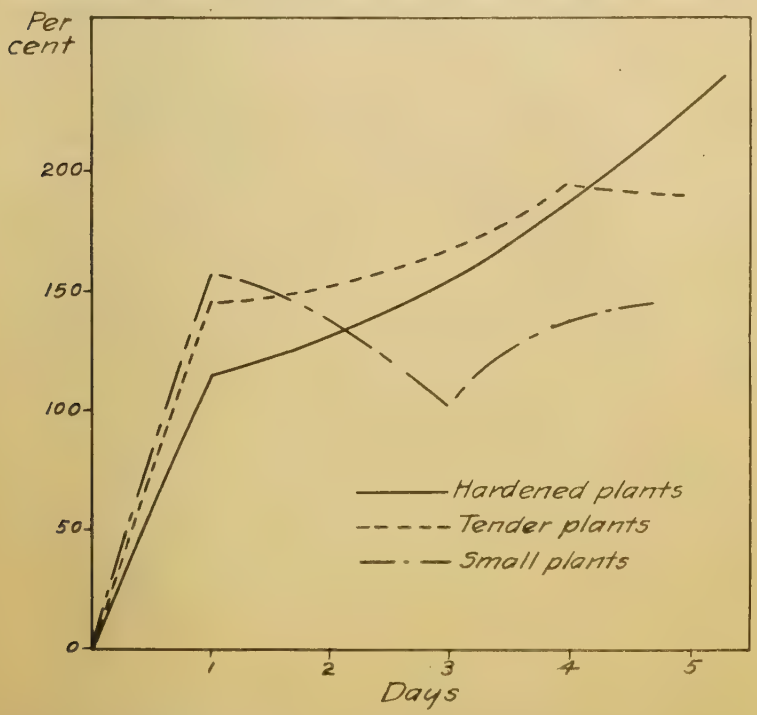

FIGURE 11. IMBIBITION BY DRIED CABBAGE PLANTS WHEN PLACED BETWEEN MOIST BLOTTING PAPER

The tendency of the per cent of water imbibed to pass through a maximum value should be noted

reducing the free water of all samples to the same value. The further objection that the rate as well as the amount of absorption may vary widely with the material or the conditions makes it extremely doubtful whether this method can be used with plant material. Some of the irregularities which were observed in swelling test work and which tend to discredit the method are indicated in figure 11 and in table 24.

TABLE 24. Variations in the Imbibition of Water by Dried Plant Tissue

Sample	Soaking treatment	Dry weight (grams)	Wet weight (grams)	Increase (per cent)
Cabbage 1	Autoclaved, soaked 72 hours	1.67	2.99	79.0
2	Autoclaved, soaked 72 hours	1.58	2.82	78.5
Cabbage 3	Soaked 48 hours	1.67	3.13	87.4
4	Soaked 48 hours	1.63	2.79	71.1
Cabbage 5	Soaked 72 hours	1.68	2.80	66.5
6	Soaked 72 hours	1.67	2.79	67.0
Lettuce 1	Autoclaved, soaked 72 hours	1.43	3.43	150.0
2	Soaked 48 hours	1.52	5.10	235.0
3	Soaked 72 hours	1.39	3.36	151.5

The absorption showed a tendency to reach a maximum value and then to drop, possibly because of leaching or bacterial action. Since the time to reach such a maximum varied with the previous treatment as well as with the kind of material, it is obviously impossible to make comparisons by this method.

Water loss from hardened and from tender plants

Inasmuch as the differences in hardening were expected to affect transpiration, direct measurements were extended when the indirect methods already outlined failed to give significant results. Rosa (1921) has reported a retardation of the rate of drying of cut cabbage plants by previous hardening treatments, with a smaller difference for tomatoes. Rosa (1921) and Boswell (1923) found the same indications with growing plants in paraffin-covered pots.

Drying of cut plants

The writer's first experiment was designed to test the rate of drying of cut plants of various sorts and of varying previous treatment. Only four plants were used in each lot, which would have made the probable error high had not the rate of loss been exceptionally uniform. The plants were suspended in large desiccators over sulfuric acid; 200 cc of 95-per-cent acid was used in the low-humidity chambers and 400 cc of 37-per-cent acid in the high-humidity chambers. The actual average humidities, under the two conditions, were 10 and 40 per cent, respectively. The humidity over the 95-per-cent acid dropped slowly from 15 per cent to 0 per cent as the plants dried, while that in the other chambers was nearly constant at 40 per cent. The plants were weighed every four

hours for the first two days and at twelve-hour intervals thereafter. The results are plotted in figures 12 to 15. Cabbage and lettuce plants, which normally show the more hardening and are more easily transplanted, gave a slower rate of loss with the higher humidity or with hardened plants; tomatoes showed little and cucumbers no influence from the varying treatments. On the other hand, the differences were not large,

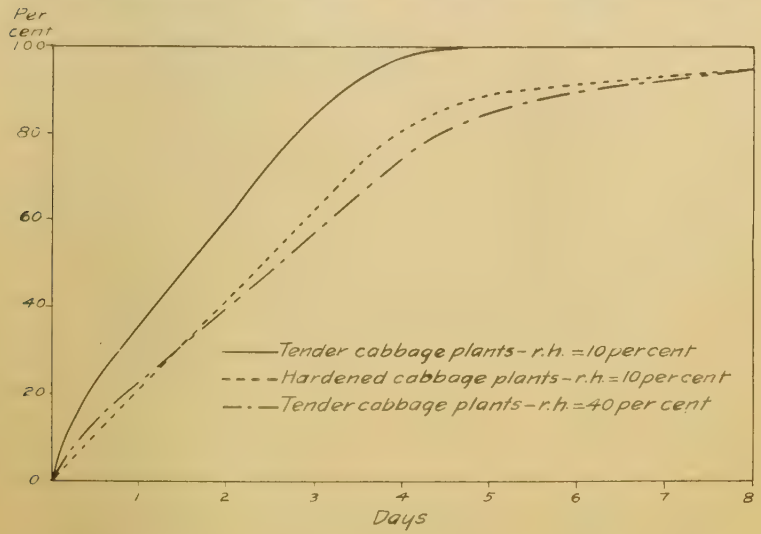

FIGURE 12. WATER LOSS FROM CABBAGE PLANTS HELD IN CONSTANT-HUMIDITY CHAMBERS

and the actual drying rate of lettuce was exceeded only by that of watermelons, while corn gave a low rate, so that the correlation between transplanting and rate of water loss under these conditions was not good.

Transpiration of living, hardened and tender vegetable plants

A series of experiments was run during the winter and summer of 1922-23 in which the plants were grown in glazed one-gallon jars which were sealed with a mixture of 20 per cent vaseline and 80 per cent paraffin while the records were being taken. Hardening was obtained by withholding water, but the moisture content of the soil was the same for all lots during the test. Water was added daily through a tube into a small inverted flower pot to maintain constant weight of the pots. While the

weights were being recorded, water was also added at noon unless the rate of loss was low. For the first experiments both the weights and the leaf areas of the plants were taken. That this was unnecessary, however, is shown in table 25. The results by the two methods are closely comparable and the factor which would be expected to cause variation, the thickening of the leaves of the hardened plants, is not apparent.

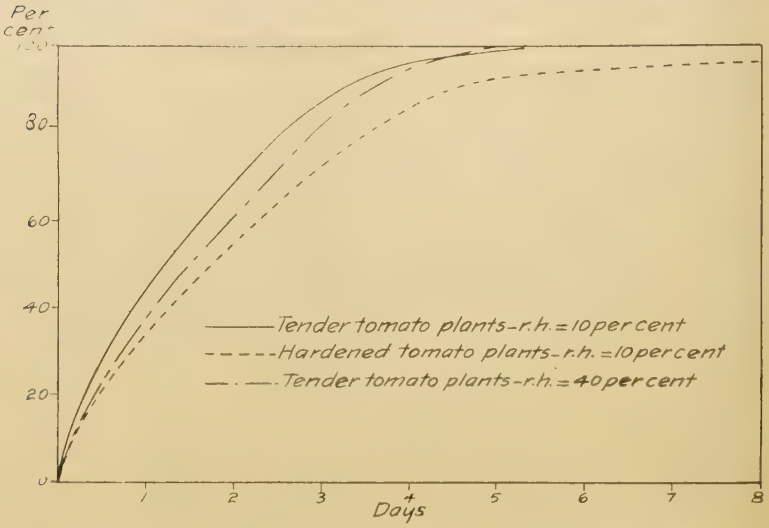

FIGURE 13. WATER LOSS FROM TOMATO PLANTS HELD IN CONSTANT-HUMIDITY CHAMBERS

TABLE 25. A COMPARISON OF GREEN WEIGHT AND LEAF AREA AS UNITS FOR MEASURING DIFFERENCES IN TRANSPIRATION

Plant	Transpiration of hardened plants, expressed as per cent of tender				Weight of 100 square inches of leaves, in grams	
	Cloudy day		Bright day			
	By weight	By area	By weight	By area	Tender	Hardened
Tomato	47.8	43.7	83.8	82.4	27.24	27.08
Cabbage	43.2	40.2	.....	.....	34.32	36.05
Cucumber	49.7	44.8	70.9	72.3	32.38	30.44

The two columns in table 24, headed "cloudy day" and "bright day," are interesting. These results were obtained with plants from the same lot on successive days. All conditions of exposure and previous treatment were the same except that the average temperature was 67° F. on the first day and 79° on the second while the relative humidity was 50 per cent and 30 per cent, respectively. The suggested explanation is that the tender plants were unable to maintain maximum transpiration under the dry conditions, even when the roots were liberally supplied with moisture.

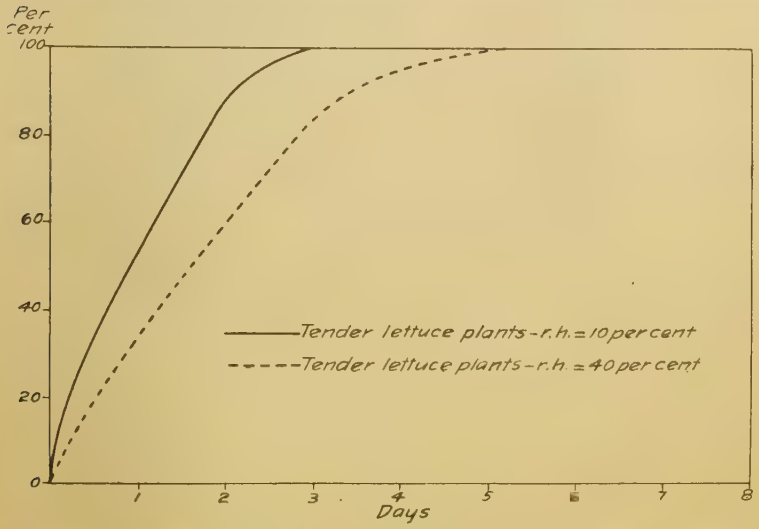

FIGURE 14. WATER LOSS FROM LETTUCE PLANTS HELD IN CONSTANT-HUMIDITY CHAMBERS

TABLE 26. TRANSPIRATION OF HARDENED AND TENDER VEGETABLE PLANTS

Plant	Weight of plants		Transpiration per gram		
	Tender, in grams	Hardened, in per cent tender	Tender, in grams	Hardened, in grams	Hardened, in per cent tender
Tomato	62.04	48.8	3.94 ± .06	3.70 ± .12	93.5
Cabbage	54.80	46.2	4.57 ± .13	3.28 ± .09	71.0
Cucumber	53.60	42.0	4.62 ± .10	4.27 ± .08	92.8

Between 11 a. m. and 1 p. m. the tomato plants lost water at the rate of 0.5 gram per gram green weight per hour and showed slight wilting although constantly supplied with water.

Another experiment run several weeks later, on May 29, gave an even smaller difference between the hardened and the tender plants. The conditions were apparently more uniform in the later run and the number of plants was ten instead of four. The results are given in table 26.

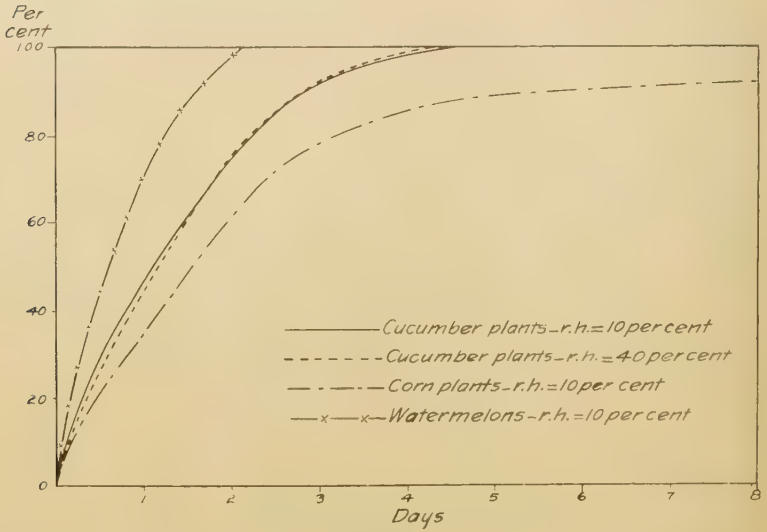

FIGURE 15. WATER LOSS FROM SOME GROUP-C PLANTS HELD IN CONSTANT HUMIDITY CHAMBERS

Only one difference in table 26, that for cabbage, is significant. These experiments show that, while there is a tendency for the rate of transpiration to be lowered by the method of hardening used, this lowering is not always marked and is more dependent upon the water supply in the leaves than upon the previous treatment of the plant and its supposed adjustments. This view is supported by a further consideration of the rate of transpiration after transplanting.

Transpiration after transplanting

A preliminary experiment to study the influence of hardening upon transpiration after transplanting was run in the winter of 1922-23. It

indicated no constant or significant lowering of the water loss in hardened plants although they gave, in some instances, a lower rate for the first two days. On the other hand, the hardened plants showed a decided tendency to recover the normal rate more rapidly than did the tender plants.

The experiment was repeated under carefully controlled conditions in the fall of 1923. The plants were grown in glazed one-gallon jars. Four plants were started in each jar, of which two were cut at the beginning of the run to determine initial size and the other two used in the experiment. Five repetitions gave ten plants in each lot. Beginning about ten days before the commencement of the run, the water supply of one lot of five pots of each of the crops was lowered until the soil was dry and the plants wilting. On the evening preceding the transplanting all pots were watered, and after transplanting additional water was added to bring them all to an optimum moisture content of 60 per cent of saturation, or about 32 per cent on a dry-weight basis. They were then sealed with a mixture of 20 per cent vaseline and 80 per cent paraffin, and the transpiration was determined by weighing at two-day intervals. Water was added at each weighing, through a tube and small inverted pot in the bottom of the jar, to bring the potometer to its original weight.

The loss of water in grams per gram green weight of tops for the third and fourth and third to eighth days, inclusive, is given in table 27. The losses during the first and second days were practically the loss from the wilting of the plants, and with a total weight of 3500 grams it is not possible to measure accurately differences of 2 to 3 grams. The appearance of the plants did not indicate any appreciable advantage at this point because of the lower water loss from the hardened plants, and it would seem that any advantage from hardening previous to transplanting can be more satisfactorily explained on other bases.

TABLE 27. TRANSPIRATION AFTER TRANSPLANTING

Crop	Initial size of plants (grams)		Transpiration, 2 to 4 days after transplanting		Transpiration, 2 to 8 days after transplanting	
	Tender	Hardened	Tender, in grams per gram tops	Hardened, in per cent tender	Tender, in grams per gram tops	Hardened, in per cent tender
Cabbage	129.3	50.5	0.50	270.0	2.87	201.0
Lettuce	140.7	52.7	0.67	125.3	3.55	180.5
Tomato	167.2	78.0	0.63	117.3	3.26	161.3
Cucumber	75.4	36.8	0.09	0.0	1.75	220.5

In every instance except the first measurement on the cucumbers, where the loss was too small to be calculated, the hardened plants transpired more per gram of green weight than did the tender plants. This higher rate had appeared by the fourth day and was maintained throughout.

At least one of the factors involved is given in table 28, where the increased transpiration is shown to be accompanied by an increased rate of root and top growth.

TABLE 28. Transpiration per Gram Tops and per Gram Roots in the Period Immediately Following Transplanting

Crop	Growth, in per cent		Root-top ratio hardened plants, as per cent tender ratio*	Transpiration for 6 to 8 days, as per cent tender	
	Tender	Hardened		Per gram, tops	Per gram, roots
Cabbage	—16 30	+45 3	148.4	206.2	139.4
Lettuce	— 1 19	+52.4	187.3	170.0	98 3
Tomato	+ 5.48	+32.9	127.1	172.3	135 0
Cucumber	—33 55	— 1.25	211.0	194 0	90 2
Average	—11.39	+32 34	168.45 ± 12.8	185.62 ± 6.0	115.72 ± 8.5

* Root-top ratio, as used here, means the weight of roots expressed as per cent of green weight of tops. This ratio was sixty-eight per cent higher for the hardened plants than for the tender at the end of the run.

Several interesting relations are indicated here. The transpiration per gram of tops for the hardened plants for the seventh and eighth days was 185.6 per cent of that of the tender plants. The hardened plants were making an appreciable growth, while the tender ones had not yet regained their initial weight. The hardened plants were producing new roots more rapidly than the tender plants, and this increased root growth seems to have been responsible for the increased water loss. A value of 100 instead of 115.7 in the last column would indicate perfect correlation between mass of roots and transpiration at this stage. Even when the limited range of the experiment and the fact that mass may not be the best measure of the absorptive area of a root system are considered, the correlation is highly suggestive if not entirely conclusive.

These indications led to two larger experiments which considered only the recovery after transplanting, as shown by top growth, and the correlation between root replacement and such growth.

Root replacement by hardened and tender plants

The plants for these experiments were grown in the same manner as those for the transpiration experiments, and were handled in the same way except that the surface of the pots was not sealed, since no attempt

was made to measure transpiration. One lot of ten plants was taken up at the beginning of the run as a check. These plants were lifted exactly as though they were to be transplanted, and the green weight of roots and tops was obtained. The ratio between the tops and the roots obtained with the plants was taken as the "as transplanted" ratio. The roots remaining in the pots were washed separately, and the ratio between tops and total roots is the "check" ratio. As in previous experiments, the pots were uniformly watered the evening before transplanting and thereafter.

In the first experiment the first lot of transplanted plants was taken up at seven days and the second at fourteen days. The percentage of growth, as shown in table 28, was greater in the hardened lots, but the intervals were too long for a satisfactory study of root replacement. Replacement was well advanced in both the hardened and the tender plants at the end of seven days, and was in most cases above the values of either the check or the fourteen-day reading.

TABLE 29. GROWTH OF HARDENED AND TENDER PLANTS AFTER TRANSPLANTING

Given as per cent green weight of check at beginning of experiment

Time after transplanting	Cabbage		Tomato		Cucumber	
	Tender	Hardened	Tender	Hardened	Tender	Hardened
7 days	—15.90	—21.00	+65.10	+96.30	+72.40	+97.50
14 days	+74.80	+126.80	+177.50	+404.00	+177.00	+196.80

The experiment was repeated under the same conditions, except that a larger number of pots were used and lots of ten plants were taken up three, six, and nine days after transplanting, to determine more accurately the progress of top growth and root replacement.

TABLE 30. GROWTH OF HARDENED AND TENDER PLANTS AFTER TRANSPLANTING, SECOND EXPERIMENT

Data as per cent of green weight of check at time of transplanting

Time after transplanting	Cabbage		Tomato		Cucumber	
	Tender	Hardened	Tender	Hardened	Tender	Hardened
3 days	+23.40	— 2.90	— 4.57	+ 5.26	—18.90	— 9.30
6 days	+33.50	+17.10	— 9.50	+20.50	—24.20	— 5.20
9 days	+99.80	+113.80	+49.10	+94.10	—14.90	+17.60

In this test the hardened tomatoes and cucumbers started growth distinctly faster than the tender plants. The hardened cabbage started top growth somewhat slower but, as shown in table 31, made a more rapid root growth, and their ratio at six days was nearly twice that of the tender plants. This is followed by the sharp rise in the growth curve for this lot between six and nine days. The cabbage was probably too thoroughly hardened for best results. The maximum difference for the other two crops was obtained at nine days.

TABLE 31. Root Replacement by Hardened and Tender Plants

Expressed as root-top ratio, $\frac{100\ R}{T}$

Time	Cabbage		Tomato		Cucumber	
	Tender	Hardened	Tender	Hardened	Tender	Hardened
Check	5.93	8.73	10.40	11.66	16.61	11.47
As transplanted	2.40	2.52	4.76	4.29	3.06	1.69
After 3 days	2.97	4.05	6.11	4.92	4.58	1.72
After 6 days	3.82	6.37	7.51	7.31	7.73	5.70
After 9 days	11.45	11.90	16.36	21.18	10.35	15.01

Work of this sort is subject to a high error, both because of the normal variability of root and top ratio and because the comparisons are necessarily indirect. The hardened plants tended to form new roots and to grow more rapidly, but one can not say that the data are decisive enough to justify the recommendation of hardened plants on this basis. Even when the hardened plants made a considerably larger percentage of growth, it must be remembered that this percentage is based on an initial size which is roughly one-half that of the tender lots, so that the hardened plants were still distinctly the smaller after the tender had become well established and had started rapid growth.

Carbohydrate accumulation during hardening

It has been shown that hardening cannot be depended upon to reduce transpiration after transplanting, but that there is a tendency for the hardened plants to transpire more and that this increase is correlated with more rapid root replacement. This would suggest that the foods accumulated during hardening are used in root growth. To test this, samples were taken of all the lots of plants used in the second experiment on root replacement. The samples were dried at 80° C. in a ventilated oven, and duplicate 1-gram portions were used for the determination of total carbohydrates by the taka-diastase method. The material was

autoclaved with 50 cc of water for two hours at fifteen pounds pressure, and digested for fourteen hours with a solution containing 0.1 gram taka-diastase. Neutral lead acetate was used in clearing and sodium sulfate for deleading. Munson-Walker heating conditions were observed, and the copper was weighed as cuprous oxide. The figures are to be taken as relative rather than absolute because the maltose formed from starch by taka-diastase was determined as glucose without hydrolysis.

Determinations of total nitrogen were also made. In the transplantable crops, cabbage and tomato, there was a drop of 0.3 to 0.8 per cent on a dry-weight basis in the first three days after transplanting, and a gradual recovery. The drop was more marked in the tender plants where the gain in dry weight was greatest and may be shown to have been due to this factor. The cucumbers gave no consistant variation in either nitrogen or carbohydrates.

TABLE 32. THE ACCUMULATION OF CARBOHYDRATES DURING HARDENING AND AFTER TRANSPLANTING

Found as glucose and expressed as per cent of green weight

Time after transplanting	Cabbage		Tomato		Cucumber	
	Tender	Hardened	Tender	Hardened	Tender	Hardened
Check	0.097	0.79	1.22*	1.40	0.27	0.38
3 days	0.74	1.00	1.55	1.68	0.36	0.36
6 days	0.31	0.38	0.63	0.89	0.20	0.25
9 days	0.24	0.19	0.28	0.26	0.23	0.26

* The high value is due to the plants having grown large for the pots and consequently run below optimum moisture.

If the practice of hardening previous to transplanting is to be advocated upon the basis of the beneficial effect of the increased carbohydrate reserve, table 32 indicates that a very small amount of hardening will be sufficient. Unfortunately, no low value was obtained in the check tomato for the reason already given. The increase, in three days, of 700 per cent in the reserve of tender cabbage indicates, however, that maximum benefits from hardening may be obtained in a very short time, and may explain some of the irregularities in the work on hardening and root replacement in which the plants were thoroughly hardened, probably beyond any required or desirable point. It is difficult to draw conclusions from the uniformly low carbohydrate values obtained with cucumbers because of the lack of specificity in the analytical methods used. The very small increase with hardening may, however, be a link in the chain of slow root replacement and poor resistance to transplanting exhibited by this plant.

STUDIES OF ROOT GROWTH AND ROOT STRUCTURE AS AFFECTING TRANSPLANTING

Root replacement and its relation to transplanting

The preliminary work in the experiments on root replacement suggested that rate of root replacement in various vegetables might show better correlation with ease of transplanting than had any of the factors studied. An experiment on this phase of the problem was consequently started in the spring of 1923. Twelve vegetables were used, of which four were considered as being easily, four moderately easily, and four difficultly transplanted, after the grouping used in table 2. The experiment was duplicated with plants of two sizes. In the first experiment, the plants were somewhat smaller than the six-week stage and ranged in age from two weeks for beans to eight weeks for celery. These plants were handled in 3½-inch pots with eight pots in each lot. Eight plants were cut at the beginning of the run and from them the initial check ratio obtained; sixteen were transplanted in place with a small amount of soil and used for the four- and eight-day recovery ratios. A final lot was left untransplanted as a measure of the normal rate of growth and of the recovery of the transplanted plants.

In taking records the tops were cut at the surface of the soil and weighed immediately to 0.05 gram. The roots were then washed carefully and pressed between blotting paper to remove free moisture. Roots branching from buried portions of the stem were separated and the stem discarded down to the original, or histological, union between top and root. The fleshy roots of beets and carrots were also discarded, since it was desired to measure as nearly as possible the active root mass. The roots were then weighed without exposure to drying. The second experiment was handled in the same way except that 5-inch pots were used.

Only the comparison between the lot taken up eight days after transplanting and the original, or zero, check is given in table 33. The column headed "check ratio" gives the averages of the four check lots, zero- and eight-day small and zero- and eight-day large, and is included to show the normal proportion between roots and tops. Such a figure will indicate something of the relative root loss in transplanting where the form of the root system is the same, but is perhaps more valuable as an indication of the absorptive activity of the different roots per unit mass. Obviously, if the normal root system of cabbage weighs 15 per cent as much as the top, while that of corn is 60 per cent as heavy, the cabbage roots must be more active in absorbing water or a larger portion of the root surface must be active, for the water requirement of corn is not four times that of cabbage. This topic will be discussed again under root structure.

The remaining columns of table 33 give the root and the top weights of the plants eight days after transplanting, as percentages of the original checks. A value of 200 per cent for both roots and tops, as is found in

TABLE 33. ROOT REPLACEMENT AFTER TRANSPLANTING

All data as percentages of green weight

Group and crop	Check ratio	8-day plants, as per cent of original check			
		Small		Large	
		Roots	Tops	Roots	Tops
Group A					
Cabbage	14.49	171.0	247.1	96.8	130.5
Tomato	19.14	203.7	266.0	87.7	156.8
Lettuce	21.33	279.7	287.2	101.0	161.7
Beets	12.76	214.5	221.0	96.1	140.6
Group B					
Peppers	53.25	45.5	100.0	45.5	125.6
Onions	38.08	.....	.....	19.7	84.7
Carrots	38.76	79.5	103.9	16.0	104.3
Celery	71.82	52.4	142.5	24.9	130.2
Group C					
Cucumbers	32.76	58.6	114.7	20.1	113.3
Beans	46.07	107.2	136.2	.....	.....
Melons	30.95	33.3	157.2	60.7	115.0
Corn	66.29	90.3	168.6	35.3	126.0

the small plants of group A, indicates a very rapid recovery from transplanting, while the root percentages of the large plants in groups B and C denote essentially the proportion of the root system retained in transplanting, since there was a negligible amount of replacement in any of these lots. This work is open to the inevitable objection that the comparisons are indirectly derived, but the differences are too large and too consistent to be ruled out on this score.

The average values for the three groups, with the errors involved in averaging, are given in table 34. These errors are large because of the small number of variants considered and the unavoidable variations in

TABLE 34. SUMMARY: ROOT REPLACEMENT AFTER TRANSPLANTING

Group	Check ratio	8-day plants, as per cent of 0-check					
		Small			Large		
		Age (weeks)	Roots	Tops	Age (weeks)	Roots	Tops
A	16.9±1.3	5	217.2±15.4	255.3±9.5	7	95.4±1.9	147.4±4.9
B	50.5±5.3	7	59.1± 2.2	115.4±9.3	13	26.5±4.4	111.2±7.1
C	44.0±5.5	3	72.3±11.1	144.2±8.0	7	38.7±8.0	118.1±2.7

the material due to the impossibility of obtaining the same proportion of roots with the different plants at the time of transplanting. Some plants, particularly after an early transplanting or when confined in pots, produce a matted root system branching freely from the plant, while others produce a few main roots which do not branch profusely except near the tips. These differences mean that a larger proportion of the matted type of root system is moved in transplanting and an apparently more rapid replacement is obtained.

An unquestionably significant difference between group A and group B or C, on every point compared, is shown in table 34. The largest

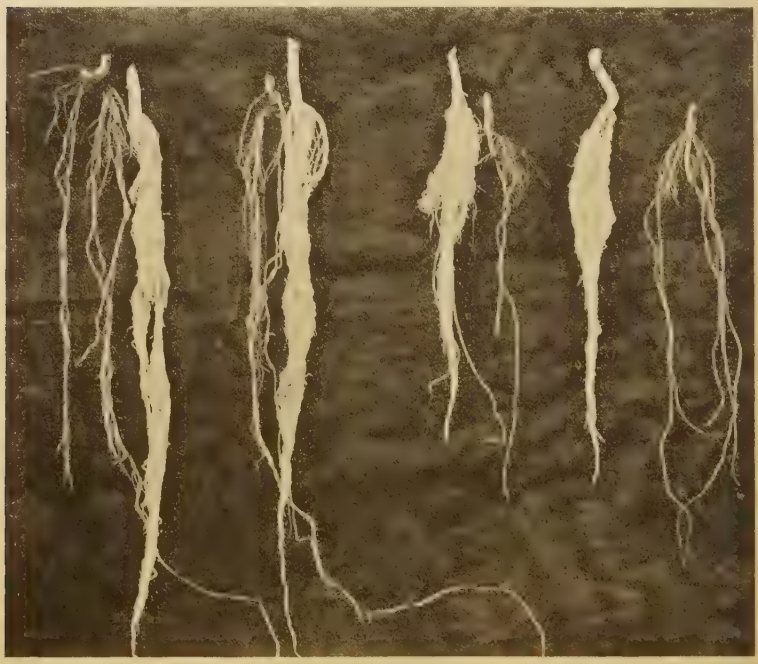

FIGURE 16. ROOT REPLACEMENT ON EIGHT-WEEK-OLD CABBAGE PLANTS AND ON TWO-WEEK-OLD CORN PLANTS

Left, check; right, eight days after transplanting. This shows that the cabbage plants have produced a large number of new root tips from the cut ends of the old roots, while all growth in the corn is from the uninjured, secondary roots forming at the first node. If these roots are removed, corn cannot be successfully transplanted

FIGURE 17. ROOT REPLACEMENT ON THREE-WEEK-OLD BEAN PLANTS

Left, check; right, eight days after transplanting. Compare the amount of root replacement with that on the older cabbage plants shown in figure 16

probable error in the table is that for the roots of the large plants in group C. This error of 31 per cent is due chiefly to initial variations in the proportion of roots retained in transplanting. From column one we would also expect that the average proportion of roots transplanted in group C would be higher than in group A, since the normal ratio in group C is nearly 300 per cent of that of group A. In spite of these difficulties, the odds that the difference between the replacement of large plants in groups A and C is significant are about 400,000 to 1. This agrees with observations made during the experiment, which showed, after eight days, practically no new growth on the group-C plants except from a few uninjured

root tips, while the group-A plants formed new growing points freely and made a growth of 2 to 5 inches. The mass and a large part of the length of the small, group-A plants were replaced in four days, while no signs of replacement were visible in group C. In most cases little more than a start has been made by these plants after eight days, although they were only three weeks old when transplanted. (Figure 17).

The classification which has been used may not hold in every instance, but the general premise, that recovery from transplanting is chiefly dependent upon rate of new root formation, would seem to be well founded. Some of the observed variations in rate of new root formation and root replacement are illustrated in figures 16 and 17.

Another point of interest in table 34 is the rapid drop in rate of root replacement with increasing age. This appears in about the same proportion in all groups, and may be shown from the data given to be safely significant for the first two groups. More extensive work would undoubtedly give the same results for group C. This is directly in line with the experiments on time of transplanting, where it was shown that the check from heavy root pruning was proportional to the size of the plant. The rate of replacement in the three groups would, if plotted form three roughly parallel lines. The rate does not decrease more rapidly in group C, but merely starts at a lower value. This suggests that some similar process is concerned, which starts at an earlier period in those plants which are not easily transplanted. Such a process might consist of structural changes in the roots which would retard or inhibit the development of new branches from the older parts of the root system.

Studies of the cutinization and suberization of the roots of certain vegetable plants

The work on the cutinization and suberization of the roots of vegetables was initiated early in the progress of the study, on the theory that differences in structure, and particularly in amount of cutinization or suberization of the older roots, might affect the ability of the plant to obtain the necessary water supply in the first few days after being transplanted. As the work on replacement progressed, it seemed that there might possibly be a correlation between the rather distinct differences in rate and amount of suberization and the decided differences in root formation, and the observations were extended to study this point.

After trying sodium hydroxide and zinc chloro-iodide, alkannin, and iodine and sulfuric acid, Sudan III was chosen as the most satisfactory stain for suberized or cutinized tissue. When the material had not been preserved too long, this stain gave a bright to medium orange color in suberized cells and a rose color to other tissue. For rapid observations a freehand section of the material was placed on a slide and wet with a drop of concentrated sulfuric acid. The suberized cells were stained brown, while unprotected tissues were rapidly destroyed.

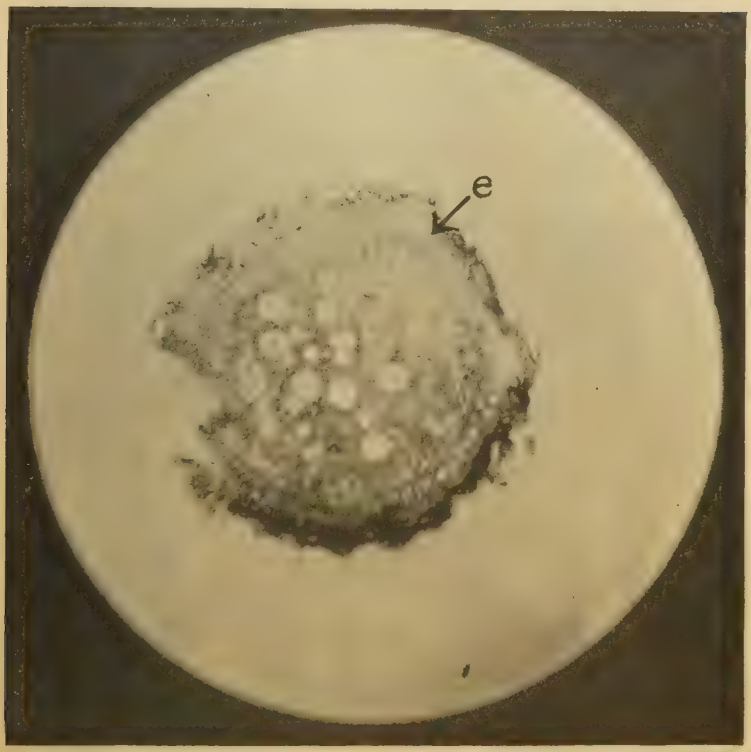

FIGURE 18. SECTION OF SIX-WEEK-OLD TOMATO ROOT

This shows absence of suberization in the endodermis, *e*, and very weak cutinization. Tomato is a group-A crop

Observations were made upon a large number of vegetables and upon roots of different ages and sizes. Depending upon the amount of secondary growth, one of two general types of waxy deposits was found. In the monocots, of course, and also in the legumes, the endodermal layer persists strongly and becomes heavily suberized at an early stage in the development of the root. In the cucurbits and some of the other plants studied, notably celery, a periderm layer develops from the pericycle, cutting off

the endodermis and cortex. This layer was also heavily suberized. No periderm was observed in the tomato, although a protective layer is presumably formed in the old roots. There were, however, no evidences of such a layer in roots eight weeks old. Six-week-old cabbage and lettuce roots showed a light periderm layer, while peppers and eggplants showed some endodermal suberization and a tendency toward moderately early periderm formation. The roots of peas, beans, and corn show endodermal suberization within a short distance of the growing point, and the cortex

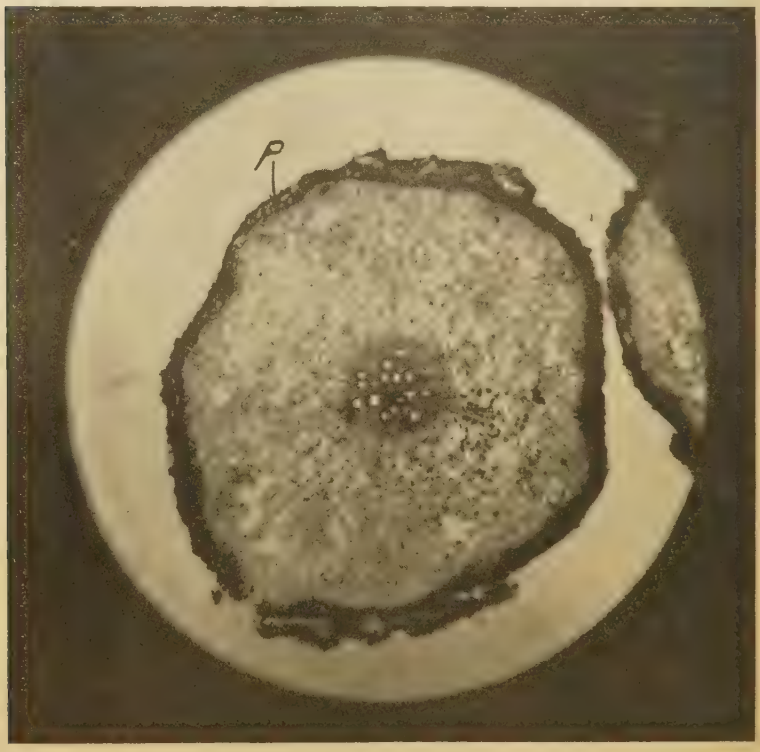

FIGURE 19. SECTION OF EIGHT-WEEK-OLD CELERY ROOT

This shows parenchymatous growth in the pericycle and the formation of a heavily suberized periderm. *p*, in a group-B crop

FIGURE 20. SECTION OF SIX-WEEK-OLD ROOT OF MELON
This shows the formation of a distinct periderm in a group-C crop

is apparently cut off from the stele in the course of a few days. The persistence of the cortical tissue, however, suggests that the separation is not so complete as it appears. The different types of suberization observed are illustrated in figures 18 to 21.

The vegetables used in the root-replacement studies, together with the normal root and top ratio as given in table 33, an index of root replacement for the large plants from the same experiment, and the relative amount of endodermal or exodermal suberization, are given in table 35.

The differences between group A and groups B and C are distinct, and a relation between suberization and ease of transplanting seems

TABLE 35. Relation of Suberization to Root Activity and Replacement

Group and crop	Normal ratio	Replacement index*	Relative suberization or cutinization†
Group A			
Cabbage	14.49	+3.41	1
Tomato	19.14	+2.02	0
Lettuce	21.33	+2.23	1
Beets	12.76	+3.20	1
Average	16.93	+2.72	0.75
Group B			
Peppers	53.25	−0.43	2
Onions	38.08	0.00	2
Carrots	38.76	−0.45	2
Celery	71.82	+0.30	3
Average	50.48	−0.15	2.25
Group C			
Cucumbers	32.76	−0.05	2
Beans	46.07	.....	3
Melons	30.95	−0.20	3
Corn	66.29	..	3
Average	44.02	−0.13	2.75

* Increase of root length in inches between fourth and eighth days after transplanting.
† 0, suberization not observed; 1, light; 2, moderate; 3, heavy.

probable. More work on the mechanism of the formation of branch roots is needed, however, before the meaning of the apparent correlations between suberization and root replacement can be explained. The stimulation for root formation is internal and presumably a matter of nutritional balance; the meristem is active in those plants showing secondary growth, at least, and it is not clear how an external periderm layer could affect the initiation of branch roots unless it were by reducing the water supply and thereby the turgor of the tissues concerned. Those plants which show little or no protective covering on the younger roots have shown a tendency to start top growth some time before the normal root ratio is reestablished, and in some cases before there is any noticeable formation of new root points, which is a better index of replacement than mass. This indicates that, even after most of the younger and more active parts of the root system have been removed, the plant is still able to obtain a fair supply of moisture, and this may be the cause underlying the connections observed. The plants having heavily suber-

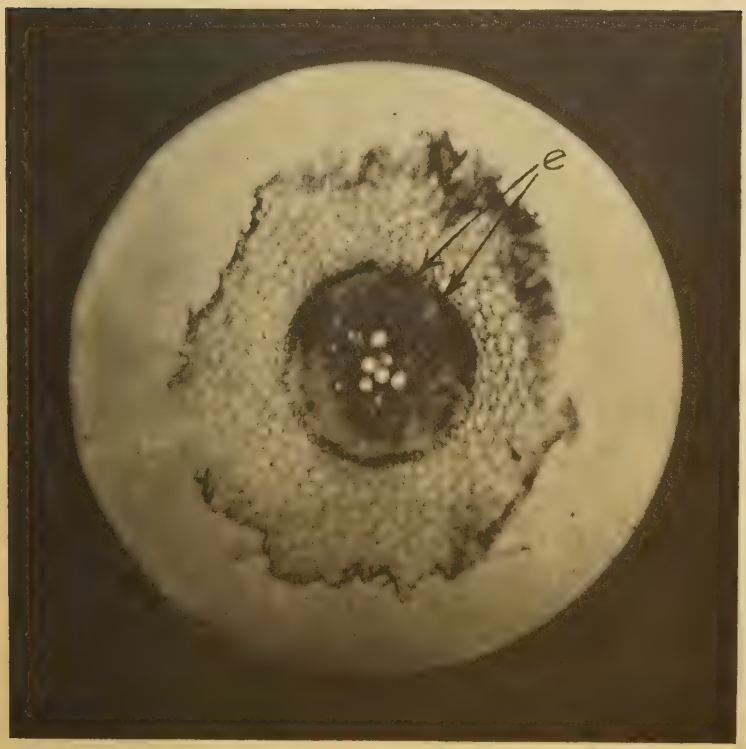

FIGURE 21. SECTION OF THREE-WEEK-OLD ROOT OF BEAN
This shows distinct suberization in the endodermal layer, *e*, of a group-C crop

ized roots apparently do not make an appreciable growth until after new roots have been formed. When the tops are turgid enough for growth, the roots should certainly not be suffering for lack of moisture. On the other hand, with a very slow movement of water from the soil into the roots, the tops may remove the moisture rapidly enough to cause a deficiency in the roots. It is not likely that this is the only factor involved, but the fact that transplanted plants recover more rapidly under low transpiration conditions tends to support its importance.

DISCUSSION

Although strongly recommended by the older gardeners and many of the earlier writers on the subject of vegetable growing, there seems at present to be considerable doubt in the minds of growers concerning the advisability of giving more transplantings than are required in the most economical production of the crop. That is, the tendency is away from transplanting as a cultural practice toward transplanting as a matter of economics. Certain crops, as early lettuce and cabbage or tomatoes, are transplanted in order to grow them out of the normal season for a given locality. Tomatoes, sweet potatoes, and similar vegetables may also be grown in higher latitudes if the plants are started with artificial heat. The use of artificial protection usually requires transplanting, because it is most convenient to have the plants concentrated into a small area while the protection is being given. The same is true when special care in cultivation, watering, protection from insects, and so forth are required by the seedling plants. A third factor, which accounts for most of the transplanting in greenhouses and some of that done in intensive cultivation, is the saving of space and of expensive seeds. For these reasons transplanting will be practiced as long as profitable crops can be produced by the method. On the other hand, it is an expensive operation and not to be performed unnecessarily.

The data in this report give several indications which may help to clarify the question of the physiology of transplanting and thus serve as a guide in economic considerations. Whenever possible, the data have been analyzed mathematically. Such analysis seems justified by the fact that some observed average differences as great as 30 per cent, in the early work, were shown not to be significant by a consideration of the odds. Upon repetition of the same experiment no differences were observed. Where the early work gave significant odds, the conclusions have been borne out by subsequent experiments.

The problem is considered in three sections: growth responses in top and root, characters of the top which may be concerned in transplanting, and variations in root structure and behavior which may affect the recovery of transplanted plants.

Growth responses following transplanting

The immediate effect of transplanting is to slow down or stop the growth of the plant for a period which apparently varies directly with the amount and duration of the reduction of the water supply. When a large proportion of the active root system is retained and adequate moisture supplied, there may be very little effect from transplanting. On the other hand, with more susceptible plants and more rigorous treatment the check may be severe and permanent. Recovery from transplanting is affected by a large number of environmental and internal conditions,

but the writer has found no such factor which does not appear to be based, in its final effect, upon a change in the water supply of the plant. The amount of suberization of the older roots, the proportion of the root system normally retained in transplanting, the rate of new root formation, adaptations of the top to prevent water loss or increase resistance to death by sudden wilting, as well as soil moisture, temperature, and other factors which may be concerned in the recovery of a plant from transplanting, all affect growth through the water supply. If, after transplanting, the plant, because of the abnormal accumulation of carbohydrates or other products, develops an excessive number of main root branches with a consequently reduced vigor and spread, or if it becomes stunted, either through structural changes such as lignification or through permanent changes in metabolism, these are still fundamentally the effects of a reduced water supply. Transplanting is, however, not the only operation or condition affecting water supply, and it is not surprising that there are variations in the response to this treatment.

Another factor which must be considered in a quantitative statement of the effect of transplanting is rate of growth. If, in two plants, top growth is stopped for a week but the control plant in the first instance makes a 300 per cent growth and in the second only 50 per cent, the results as a percentage of the control plant will be very different. Again, although evidence has been advanced by various writers to show that growth tends to vary directly with initial size, there are more opportunities for differences due to transplanting to be obscured by other influences in the slowly growing plants.

Leaf characteristics influencing the effect of transplanting

The small differences observed and the magnitude of the errors raises a question of the efficiency of hardening in reducing transpiration. Transpiration may apparently be significantly reduced by previous hardening treatments only when the rate of loss is low and reduction is not an important matter. Under conditions favoring rapid transpiration, water supply becomes the limiting factor, and differences between hardened and tender plants tend to disappear. The water supply concerned is the supply moved to the leaves. A reduction of the moisture content of tender leaves insufficient to cause noticeable wilting may more markedly affect the transpiration rate than all the hardening which can be given the plant.

There is, however, an important relationship between hardening and transplanting in the resistance of the hardened plants to death by drying. In those plants which are not capable of being hardened the intracellular moisture necessary to maintain life is less strongly held, and with the great reduction in water supply following transplanting the older leaves or, in extreme cases, the entire plant may be killed by drying.

Root characteristics influencing the effect of transplanting

It follows from the statements that the effect of transplanting is mainly one of water supply and that this is only slightly influenced by the tops, that the roots are the most important factor involved in resistance to, or recovery from, transplanting. There are apparently three factors concerned: the proportion of the root system retained in transplanting, which depends upon the size of the plant and the character of the root branching; the effectiveness of the retained roots in absorbing water during the first few days after transplanting, an effect presumably correlated with the amount of suberization in the older roots; and the rate of new root formation, which depends upon the kind of plant, its age, and possibly upon the amount of accumulated food.

The following plants were most thoroughly studied in the root-replacement work and are also representative of the crops used in the other experiments.

Group A	*Group B*	*Group C*
Cabbage	Peppers	Corn
Tomato	Onions	Beans
Lettuce	Celery	Melons
Beets	Carrots	Cucumbers

The plants listed in group A are commonly transplanted or easily survive this treatment, those in group B require more care in handling, and those in group C are not transplanted in the ordinary manner. The experiments performed may be summarized in terms of these three groups. These summaries, whenever they are available for the three groups, are given in table 36, together with the odds that the differences between the comparisons A — B, A — C, and B — C are significant.

TABLE 36. A SUMMARY OF THE FACTORS STUDIED AND THEIR CORRELATION WITH EASE OF TRANSPLANTING

Experiment	Group			Odds that		
	A	B	C	A>B	A>C	B>C
TL plants as per cent of check, table 3	69.1±5.2	64.5±0.9	38.5±3.9	<1 to 1	650 to 1	>10,000 to 1
Per cent surviving 14-day drying, table 20	83.9±4.0	41.7±16.8	0±0.0	9 to 1	∞	∞
Freezing-point differences for hardened and tender plants, table 22	0.254°±.016	0.231°±.048	0.154°±.013	<1 to 1	1,050 to 1	2.2 to 1
Root replacement, small plants, table 34	217.2±15.4	59.1±2.2	72.3±11.1	∞	∞	<1 to 1
Root replacement, large plants	95.4±1.9	26.5±4.4	38.7±8.0	∞	∞	<1 to 1

Group A is higher than group C in resistance to transplanting tests and in every factor studied which might explain such resistance. Group B is above C only in resistance to transplanting. On the other hand, it is not significantly lower than group A on any score but that of root replacement. In other words, group-A plants have advantages in hardening, root replacement, and amount of suberization to explain their greater resistance to transplanting, while only actual transplanting tests indicate that celery, onions, peppers, and similar plants are more easily transplanted than corn, beans, and cucurbits. As explained under the classification, group-B plants are not highly resistant to unfavorable conditions. Celery will die and peppers or eggplants be permanently stunted if the weather is hot and dry and the soil moisture low when they are transplanted. On the other hand, the crops in this classification grow slowly, and if weather conditions are favorable they will hold on for the ten days or two weeks necessary for new root formation without serious injury either in terms of untransplanted plants or in terms of permanent stunting. They may, therefore, be classified as moderately easily transplanted, while plants which recover equally soon in point of time are more injured because a rapid development has been halted. This not only means a greater percentage loss but means that metabolic processes have been more seriously deranged, and these changes may be of such a nature as to alter permanently the development of the plant.

CONCLUSIONS

1. The immediate effect of transplanting is a reduction in the water supply, and the immediate and long-time results are dependent upon the severity and duration of such reduction.

2. It follows from *1* that large plants will be more seriously injured by transplanting than small ones because the proportion of roots retained will be less. It follows, also, that those plants having root systems of such a form as to be largely lost in transplanting or whose older roots are heavily suberized so that they must depend upon the outer portions of the root system for their moisture supply, will be more seriously injured than plants having a more branched and less heavily suberized root system.

3. No well-defined relation between the rate of water loss from the top and the ease of transplanting has been established. As an average, however, those plants which are the more easily transplanted are capable of being more thoroughly hardened. The value of such hardening probably lies more in the increased retention by the cells of the moisture necessary to maintain life than in its effect upon transpiration. Hardening may also build up a food reserve which is later used in replacing the mutilated root system. Both factors are probably active in certain plants.

4. The general trend of the work indicates that the rate of new root formation is the most important consideration in the reestablishment of

transplanted vegetable plants. Other factors, such as the absorptive capacity of the transplanted root system, the resistance of the top to death by wilting, the rate of growth, and the susceptibility of the plant to stunting, are important only as they tend to bridge the gap between one root system and the next or as their action is allowed to continue because of a slow rate of replacement.

5. Transplanting may be a very important factor in saving valuable greenhouse or garden space, in allowing for better care of slowly developing seedlings, or in saving time or seed. While there are isolated instances of crops which appear to have made a thriftier growth after an early transplanting, these instances will seldom bear statistical analysis, and the conclusion that transplanting is a harmful but frequently necessary operation seems to be required. On the other hand, the field data do not justify a large expense to avoid early transplantings, since the only shift which has consistently affected either earliness or total yield in cabbage and tomatoes is the final one to the field. The use of pots at this stage has produced earlier crops but has not had an important effect upon total yield.

6. In the case of commonly transplanted crops which are handled when not too large and under favorable conditions, the effect of transplanting seems to be proportional to the check in the growth of the transplanted plants. When growing plants in the greenhouse this difference may be overcome by earlier sowing and is frequently lost, even in experimental work, by slight differences in watering or other conditions. It would not, therefore, seem to be important. Heavy root pruning of larger plants, transplanting under unfavorable conditions, or moving crops whose rate of root replacement is very slow may seriously retard maturity and, with crops slow in root replacement, may result in permanent stunting.

SUMMARY

1. The problem of transplanting was attacked from two angles: first, its effect upon various vegetable crops and, second, physiological or morphological differences which may explain such effects.

2. Transplanting was formerly considered beneficial in itself, but is gradually coming to be recognized as an economic expedient not directly promoting the development of the plant. This latter view is borne out by the work reported.

3. Transplanting work done in greenhouse beds indicated that all vegetables could be transplanted with little or no injury in the early seedling stage. With advancing maturity the injury increased in all cases, but more rapidly in those crops poorly adapted to withstand transplanting.

4. The roots of the transplanted plants were more branched than those of the controls, the amount of branching depending upon the plant and

upon the extent of the check at the time of transplanting. Severe root pruning had no permanent effect upon root and top ratio.

5. The general effect of transplanting was to retard development, the seriousness of such retardation depending upon the plant, its age, and the conditions of transplanting. In the field work, however, the differences due to early transplanting in the house were frequently obscured by the shift to the field or by holding and hardening the plants previous to this shift. The effect of transplantings made in the field was usually clear cut. This applied both to the plants grown wholly in the field and to comparisons between the use of pots and of flats, in which the use of pots avoided serious disturbance at the time of field setting. The normal effect of transplanting was more to retard development than to decrease total yield.

6. Studies of easily, moderately easily, and difficultly transplanted crops indicated that all were equally resistant to rapid wilting at the time of transplanting, but that the first were better able to withstand unfavorable conditions afterward. This was presumably due to the more rapid reestablishment of their roots.

A study of the depression of the freezing point of the plant tissues indicated a greater change with hardening for the easily transplanted plants.

Tests with the swelling of dried plant tissue indicated that the errors of the method are too large to permit its use.

7. Studies of transpiration and of the rate of drying of incised leaves indicated that the differences between hardened and tender tissues or the correlations with ease of transplanting were not striking. Transpiration is more dependent upon the immediate water supply in the leaf than upon previous treatments when the comparisons are confined to mesophytic plants such as were used here.

8. Studies of transpiration after transplanting indicated a more rapid recovery of the normal rate in plants previously hardened. This recovery was apparently correlated with a more rapid rate of root development. The carbohydrates of the tender, easily transplanted plants were observed to pass through a maximum a few days after transplanting. This maximum corresponded roughly to the initiation of new root growth. As roots developed, top growth was resumed and the carbohydrate value rapidly dropped to normal. The high initial carbohydrate content of the hardened plants tended to shorten this adjustment period. In the one case observed, plants transplanted with difficulty did not show this carbohydrate maximum.

9. Extensive experiments clearly established a correlation between ease of transplanting and rate of new root formation. Those crops which are moderately easily transplanted showed a slow replacement but also a slow rate of top growth. Plants seriously injured by transplanting have

normally a rapid rate of top growth and a slow root replacement. Root replacement appears to be the largest single factor concerned in transplanting.

10. Observations on the structure of the older roots of a number of vegetable plants indicated that the roots of some of the more difficultly transplanted vegetables are suberized or cutinized at an early age, either in the endodermis or in a periderm layer. This may mean that the older roots of these plants are ineffective in water absorption, while similar roots of tomatoes, for instance, are capable of a limited amount of absorption during the period immediately following the removal of the root tips in transplanting. Branch formation in shortened roots seems also to be inversely proportional to the extent to which suberization has progressed.

BIBLIOGRAPHY

BAILEY, L. H., AND CORBETT, L. C. Tomatoes. Cornell Univ. Agr. Exp. Sta. Bul. 45: 187–219. (Reference on p. 202–203.) 1892.

BAILEY, L. H., AND LODEMAN, E. G. Few and many transplantings. *In* Tomatoes. Cornell Univ. Agr. Exp. Sta. Bul. 32: 150–151. 1891.

BENEDICT, HARRIS M. Senile changes in leaves of *Vitis vulpina* L. and certain other plants. Cornell Univ. Agr. Exp. Sta. Memoir 7: 271–368. (Reference on p. 338–339.) 1915.

BISHOP, W. H. Experiments with tomatoes. *In* Tomatoes. Maryland Agr. Exp. Sta. Bul. 11: 47–61. 1890.

BOSWELL, VICTOR R. Dehydration of certain plant tissues. Bot. gaz. **75**: 86–94. 1923.

BOYLE, J. G. Tomato investigations. Purdue Univ. Agr. Exp. Sta. Bul. 165: 787–830. (Reference on p. 807–814.) 1913.

BRUNK, THOS. L. Comparison of potted with transplanted tomato plants. *In* Report of the horticulturist. Maryland Agr. Exp. Sta. Rept. **4**: 407–410. 1891.

CRANEFIELD, F. The effect of transplanting on time of maturity. Univ. Wisconsin Agr. Exp. Sta. Ann. rept. **16**: 312–315. 1899.

HARVEY, R. B. Hardening process in plants and developments from frost injury. Journ. agr. research **15**: 83–111. 1918.

KNUDSON, L., AND GINSBURG, S. Suggestions with respect to the measurement of osmotic pressure. Amer. journ. bot. **8**: 164–170. 1921.

MACDOUGAL, D. T. Imbibitional swelling of plants and colloidal mixtures. Science n. s. **44**: 502–505. 1916.

MUNSON, W. M. Notes of cabbages. *In* Report of the horticulturist. Maine State Coll. Agr. Exp. Sta. Rept. **1891** (app.): 83–87. 1892.

———Report of the horticulturist. Maine State Coll. Agr. Exp. Sta. Rept. **1893** [2]: 101–144. (Reference on p. 102–103, 106–107, 113–114.) 1894.

NEWMAN, C. L. Tomatoes, cabbage and onions. Arkansas Agr. Exp. Sta. Bul. 56: 1–21. 1899.

PEARL, RAYMOND. Introduction to medical biometry and statistics, p. 218. 1923.

ROSA, J. T., Jr. Investigations on the hardening process in vegetable plants. Missouri Agr. Exp. Sta. Research bul. 48: 1–97. 1921.

TROOP, JAMES. Transplanting vs. non-transplanting. Indiana Agr. Exp. Sta. Rept. **13** (1900): 69. 1901.

Memoir 77, *A Systematic Study of the Anthomyiinae of New York, with Especial Reference to the Male and Female Genitalia*, the tenth preceding number in this series of publications, was mailed on December 18, 1924.